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MILLS AND MILLWORK.

PART II.

LONDON

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NEW-STREET SQUARE

TREATISE

ON

MILLS AND MILLWORK.

PART II.

ON MACHINERY OF TRANSMISSION

AND THE

CONSTRUCTION AND ARRANGEMENT OF MILLS.

COMPRISING TREATISES ON WHEELS, SHAFTS, AND COUPLINGS; ENGAGING AND DISENGAGING GEAR; AND MILL ARCHITECTURE; AND ON CORN, COTTON, FLAX, SILK, AND WOOLLEN MILLS; TO WHICH IS ADDED A DESCRIPTION OF OIL, PAPER, AND POWDER MILLS, INCLUDING A SHORT ACCOUNT OF THE MANUFACTURE OF IRON.

BY

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CHEVALIER OF THE LEGION OF HONOUR:
ETC. ETC.

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PREFACE

TO

THE SECOND EDITION.

It was gratifying to find that in eighteen months from the date of publication of this volume a Second Edition was required. In this we have been enabled to correct the *errata* which crept into the text, and to introduce the system of Ventilating Mill-stones during the Grinding of Corn; also to add in Appendix I. a description of Mr. Robertson's system of Frictional Gearing.

W. F.

Manchester:

September 15, 1865.

PREFACE

TO

THE FIRST EDITION.

In the First Part of this work I endeavoured to give a succinct account of nearly fifty years' experience in the profession of a mill architect, millwright, and mechanical engineer. My professional career commenced just at a time when the manufacturing industry of the country was recovering from the effects of a long and disastrous war, and I was enabled, from this circumstance, to grow up with and follow out consecutively nearly the whole of the discoveries, improvements, and changes that have since taken place in mechanical science. These discoveries have been numerous and invaluable in contributing to the development of our industrial resources, the diffusion of knowledge, and the extension of trade and commerce throughout the globe.

It will not be necessary to repeat what steam, gas, and electric telegraphs have effected both on sea and land in that time, nor how much we are indebted to these agencies for the abundant comforts, luxuries, and enjoyments which we now possess, as compared with that of the age in which our fathers lived. It will be found on inquiry that in mills, where these agencies are employed, and where the manufacture of cotton, silk, flax, and wool are carried on, are the elements to which we are indebted for the numerous advantages which enter into the improved state of our social existence. To mills, therefore, I have directed my attention, and in this volume I have endeavoured to follow up more in detail the principles of construction

and other serviceable data to which, I trust, the intelligent student may refer with some prospect of advantage.

On prime movers as comprised in water-wheels, turbines, steam-engines, &c., I must refer the reader to the First Part of this work. The present volume is chiefly directed to what is known by the name of Mill-gearing; and in Section IV. Chapter I., will be found an elaborate treatise on wheels, exhibiting the relations of diameter, pitch, width, and formation of teeth, including formulæ for calculating the strength, proportions, &c., to be observed in the construction of spur and bevel gear. Also tables of the proportions of wheels, pulleys, &c., computed from data founded upon experiments and tested in actual practice, which in some respects I believe to be more convenient and comprehensive than any hitherto published. In the same Section I have devoted a chapter to the strengths and proportions of shafts, including rules and tables for calculating their resistance to strains produced by pressure, torsion, &c., and these, with the proportions of journals, friction, lubrication, and other conditions, constitute the contents of Chapter II.

Chapter III. treats of the couplings of shafts, engaging and disengaging gear, and those connections by which motive power may be conveyed to a considerable distance from the prime mover, and by which all the necessary changes of stopping and starting machines may be effected at one part of the mill without detriment or interference with the machinery of any other part.

The first chapter of Section V. embraces a short treatise on mills and mill architecture, with illustrations, suggestions, and improvements to be employed in the construction of those edifices. I have been induced to refer to this subject from the fact, that in former times anything like architecture as applied to mills was unknown and greatly neglected; and there was a total disregard of taste or design until late years, when a few examples of architectural construction were afforded by the introduction of light cornices and pilasters, showing that it

was possible at a small cost to relieve the monotony of a large brick surface, and bring the structure within the category of light and shade. This to some extent introduced a better style of building; and on this subject I have given a few examples for the guidance of the millwright and engineer.

Chapter II. Section V. treats exclusively of corn mills; and as these constructions are chiefly in the hands of the millwright, I have been more particular in directing attention to the buildings as well as the machinery. In this department will be found several examples and illustrations of the best constructions, from those with two to others with thirty-six pairs of stones, including all the necessary machinery for cleansing, grinding, dressing, &c.

I have also given a description of the floating-mill erected for the Government during the late Crimean war; and this, with numerous details of elevators, Archimedean screw, creepers, &c., calculated to make the mills self-acting, comprise the treatise on grinding corn.

Chapters III. IV. V. and VI. are descriptive of mills for the manufacture of the textile fabrics, as comprised in cotton, woollen, flax, and silk mills. These chapters are directed more to the process of manufacture and less to details than those on corn. They, however, contain illustrations and examples of each kind of manufacture taken from mills of my own construction. They show the arrangement, but are not descriptive of the machinery, as machine making for the separate purposes of manufacture is now a distinct trade, and does not therefore enter into that of the millwright. Having omitted the machinery—which may be found in other works on that subject—I have introduced a description of the different processes as they exist in each kind of manufacture; and considering that the mechanical arrangements of which this volume treats apply generally to every description of spinning mill, its moving power, wheels, shafts, &c., being nearly the same in each, it is not necessary to multiply examples in cases where the details closely approximate and become almost identical in

form and construction. I have therefore left to others the task of describing the machinery; but I have given to oil, paper, and powder mills separate chapters. The importance of these different branches of industry establishes the necessity of their introduction, as also that of iron, which of all others is most intimately connected with the prosperity of our national industry. From the improvements in the manufacture of iron we derive advantages and facilities for construction which did not exist in former days; and it is not unreasonable that we should from this cause look forward to increased improvements in our mills, and a corresponding augmentation of the industrial resources of the nation.

In the production of this work, I have had the assistance of my former Secretary, Mr. W. C. UNWIN, now resident at Kendal; and subsequently of his successor, Mr. E. W. JACOB, who has also prepared the drawings for this volume.

W. F.

MANCHESTER:

August 18, 1863.

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ERRATUM.

Page 192, foot-note, *for* 'Appendix A' *read* 'Appendix II.'

A TREATISE

ON

MILLS AND MILL-WORK.

SECTION IV.

ON MACHINERY OF TRANSMISSION.

CHAPTER I.

ON WHEELS AND PULLEYS.

THE elementary principles of motion by rolling contact and by wrapping connectors have been explained in Section II., so that in the present Chapter we have only to examine in detail the methods of applying these principles and their respective advantages, and especially the mode of constructing wheels in gear, so that the resulting motion shall most nearly approach the condition of perfect rolling contact.

We saw in the preliminary Chapter that there were two methods of transmitting power through trains of wheel-work, the first being through the agency of wrapping connectors, and the second by rolling contact.

Wrapping Connectors.—Considerable difference of opinion exists as to the best and most effective principle of conveying motion from the source of power to the machinery of a mill. The Americans prefer leather straps,* and large pulleys or

* I have selected the word *strap*, instead of *belts* or *bands*, as a term more generally applied to wrapping connectors in the northern districts.

riggers. In this country, and especially in the manufacturing districts, toothed wheels are almost universally employed. In some parts of the South, and in London, straps are extensively used; but in Lancashire and Yorkshire, where mill-work is carried out on a far larger scale, gearing and light shafts at high velocities have the preference. Naturally, I am of opinion that the North is right in this matter, and that consistently, as I was to a great extent the first to introduce that new system of gearing which is now general throughout the country, and to which I have never heard any serious objection. I have been convinced by a long experience that there is less loss of power through the friction of the journals, in the case of geared wheel-work, than when straps are employed for the transmission of motive power. Carefully-conducted experiments confirm this view, and it is therefore evident which mode of transmission is, as a general rule, to be preferred.

There are certain cases in which it is more convenient to use straps than to employ gearing. With small engines driving saw-mills, and other machinery where the action is irregular, the strap is superior to wheel-work, as it lessens the shocks incidental to this description of work. So, also, when the motive power has been conveyed by wheel-work and shafting to the various floors of a mill, it is best distributed to the machines by means of straps.

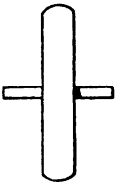
In some of the American cotton factories, however, there is an immense drum on the first motion, with belts or straps from two to three feet wide, transmitting the power to various lines of shafting, and these in turn through other pulleys and straps giving motion to the machinery. From this description it will be seen that the whole of the mill is driven by straps alone, without the intervention of gearing.

The advantages of straps are, the smooth and noiseless motion. The disadvantages are, increased friction on the journals of the shafts, cumbrous appearance, the expense of their renewal, and the necessity for frequent repairs. They are inapplicable in cases where the motion must be transmitted in a constant ratio, because as the straps wear slack, they tend to slip over the pulleys and thus lose time. In other cases, as

has been observed, this slipping becomes an advantage, as it reduces the shock of sudden strains and lessens the danger of breaking the machinery.

Very various materials are employed for straps, the most serviceable of all being leather spliced with thongs of hide or cement. Gutta percha has been employed with the advantage of dispensing with joints, but it is affected by changes of temperature, and it stretches under great strains. Flat straps are almost universally employed, in consequence of the property they possess of maintaining their position on pulleys, the edge of which is slightly convex (fig. 177). Round belts of catgut or hemp are sometimes used, running in grooves, which are better made of a triangular than a circular section—so that the belt touches the pulley in two lines only, tangential to the sides of the groove; in this case the friction of the belt is increased in proportion to the decrease of the angle of the groove.

Fig. 177.



The strength of straps must be determined by the work they have to perform. Let a strap transmit a force of n horses' power at a velocity of v feet per minute, then the tension on the driving side of the belt is $\frac{33000\ n}{v}$ lbs. independent of the initial tension producing adhesion between the belt and pulley. For example, let v be 314·16 feet per minute, or the velocity of a 24-inch pulley at 50 revolutions per minute, and let 3 horses' power be transmitted; then $\frac{33000 \times 3}{314{\cdot}16} = 312$ lbs., the strain on the pulley due to the force transmitted.

The following table has been given for determining the least width of straps for transmitting various amounts of work over different pulleys. The velocity of the belt is assumed to be between 25 and 30 feet per second, and the widths of the belts are given in inches. With greater velocities the breadth may be proportionably decreased.

TABLE I.—APPROXIMATE WIDTHS OF LEATHER STRAPS, IN INCHES, NECESSARY TO TRANSMIT ANY NUMBER OF HORSES' POWER.

Horses' Power	Smallest Diameter of Pulley in Feet								
	1	2	3	4	5	6	7	8	10
1	3·6	1·8	1·2	—	—	—	—	—	—
2	7·2	3·6	2·4	1·8	1·4	—	—	—	—
3	10·8	5·4	3·6	2·7	2·1	1·8	1·5	—	—
4	14·4	7·2	4·8	3·6	4·8	2·4	2·0	1·8	1·4
5	18·0	9·0	6·0	4·5	3·6	3·0	2·5	2·2	1·8
7	25·2	12·6	8·4	6·3	5·4	4·2	3·5	3·7	2·5
10	36·0	18·0	12·0	9·0	7·2	6·0	5·1	4·5	3·6
12	43·2	21·6	14·4	10·8	8·6	7·2	6·1	5·4	4·3
14	—	25·2	16·8	12·6	10·0	8·4	7·1	6·3	5·0
16	—	28·8	19·2	14·4	11·5	9·6	8·2	7·2	5·7
18	—	32·4	21·6	16·2	12·9	10·8	9·2	8·1	6·4
20	—	36·0	24·0	18·0	14·4	12·0	10·2	9·0	7·2
25	—	45·0	30·0	22·5	18·0	15·0	12·8	11·2	9·0
30	—	—	36·0	27·0	21·0	18·0	15·0	13·0	10·0
40	—	—	48·0	36·0	28·0	24·0	20·0	18·0	14·0
50	—	—	—	45·0	36·0	30·0	25·0	22·0	18·0
60	—	—	—	—	43·0	36·0	30·0	27·0	21·0
70	—	—	—	—	—	42·0	35·0	31·0	25·0
80	—	—	—	—	—	—	41·0	36·0	28·0
100	—	—	—	—	—	—	51·0	45·0	36·0

Toothed Wheels.—The second method of communicating motion is by rolling contact, as explained in the preliminary Chapter.* But, in practice, the adhesion between the surfaces is seldom sufficient to communicate the necessary power, and hence various contrivances—such as the wheel and trundle, and toothed wheels—have been substituted. The general equations for velocity, ratio, &c. are the same as if the wheels rolled on each other at the pitch circles, but in fact each tooth slides upon its fellow. The determination of the best forms of these teeth so that the friction shall be a minimum and the motion uniform, is one of the most important contributions of applied mathematics to practical engineering.

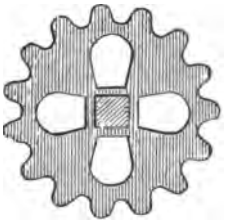
Of the introduction of toothed wheels and toothed gearing we know very little. Hero of Alexandria, who wrote two centuries before our era, speaks of toothed wheels and toothed bars in a

* Part i. page 40.

way which seems to indicate that he was not altogether ignorant of this method of transmitting motion. Later forms are figured in great variety in the different collections of mechanical appliances of the sixteenth and seventeenth centuries.

Spur gearing is employed where the axes on which the wheels are placed are parallel to one another. The smaller wheel in a combination of this sort is termed the pinion. Annexed (fig. 178) is a pinion from Ramelli (A.D. 1588), which, from its form, may be surmised to be of metal. The principle on which spur gearing is constructed is primarily the communication or motion through the rolling of two cylinders on one another. The teeth are introduced to prevent slipping, and thus to insure the regular communication of the motive power.

Fig. 178.



In the older wooden wheels, the teeth were usually formed of hard wood, and driven into mortises on the periphery of a wooden wheel. The pinions were generally replaced by trundles, in which cylindrical staves, fixed at equal distances round the periphery of two discs, were driven by the teeth of the wheel.

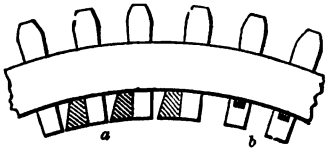
The mortise wheels are still retained in countries where iron is expensive, and even in this country they are employed in a modified form. Iron pinions, with wooden cogs fixed in the periphery, are used to receive the motion from the flywheels of engines, with a view to reduce the noise and to increase the smoothness of the motion; and many millwrights prefer, in all cases where large wheels are required to run at high velocities, to make one of them a mortise-wheel, with wooden cogs.

There does not appear to have been much improvement in the construction of wood and iron gear since it was first introduced by Mr. Rennie; the only exception being the introduction of a machine for cutting out the form of the teeth,* which in

* Mr. Smiles states, in his 'Lives of the Engineers,' that Brindley, more than a century ago, invented machinery for the manufacture of tooth and pinion wheels, 'a thing,' as stated by the author, 'that had not before been attempted, all such wheels having, until then, been cut by hand, at great labour and cost.

those days was done by hand, with keys or wooden wedges fitting into dovetails in the 'shanks' of the cogs, as shown at *a*, fig. 179, on the concave side of the rim; now they are made with an iron pin driven through the cog, close to the rim, as at *b*. The iron pinion or wheel intended to work in contact with the wood teeth was, up to a recent date, turned and carefully divided to the epicycloidal form, and then chipped and filed with great exactitude, in order to fit accurately into the wooden teeth of the driving wheel. In all the corn mills of the present day, and where great speed is required, the same attention to accuracy is observed in wood and iron gear as at former times.

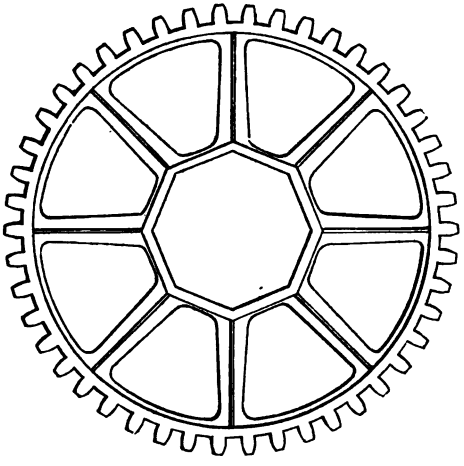
Fig. 179.



The greatest advance in the application of gearing resulted from the introduction, at the end of the eighteenth century, of cast-iron in place of wood. The credit of the introduction of this material is usually given to Smeaton, who began to use cast-iron in the construction of the Carron Rolling Mill, in 1769.

Fig. 180. Section.

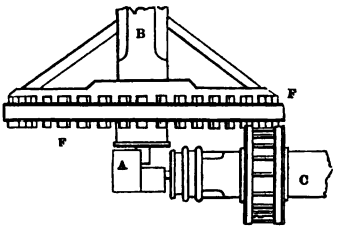
Fig. 181. Plan.



But the late Mr. John Rennie, when at Boulton and Watt's, in 1784, was probably the first to carry the use of cast-iron into all the details of mill-work. Figs. 180, 181 are copied from the original designs for the Soho Rolling Mill, dated 1785. But the Albion Corn Mills, built about the same time (1784–5), may be considered as the earliest instance of the entire replacing of wood by cast-iron for the bevel and spur wheels and shafts. This was effected by the same distinguished engineer.

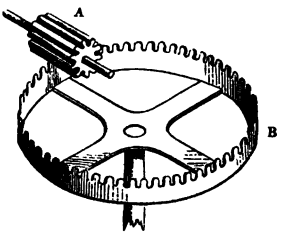
Where the shafts of the wheel and pinion are not parallel to each other, various forms of conical trundles and bevel wheels are employed. The simplest plan is probably the face wheel and trundle shown in fig. 182, which have been employed from a very early period, and which, if made of metal, take the form of the crown wheel and pinion, fig. 183. Where the axes are not at right angles, conical trundles have been used, one of which is figured in Bessoni (A.D. 1578).

Fig. 182.



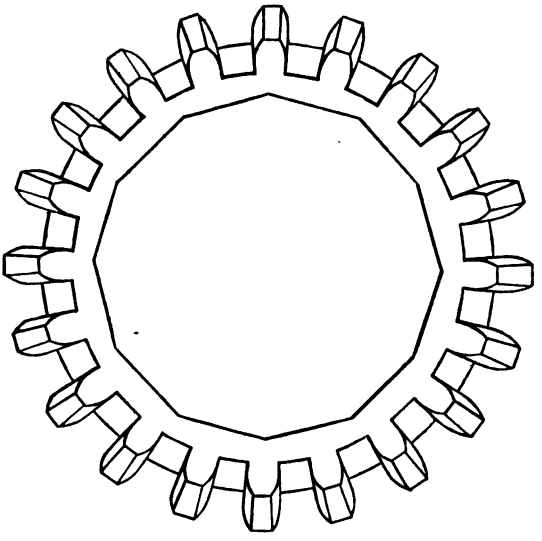
The most perfect arrangement, however, is that in which two wheels called bevel wheels are employed, constructed in the form of frustra of cones. These were not introduced till the middle of the last century, the principles of the construction of the teeth being due to Camus (A.D. 1752). Fig. 184 shows a bevel wheel designed for the Rolling Mill at Soho, by the late Mr. Rennie, in 1785.*

Fig. 183.



* It is evident from the shape of the eye of these wheels, figs. 180, 181, and 184, that they were intended for wooden shafts, and that cast-iron had not been in use much before that time. At an earlier period, Mr. W. Murdock, of Soho, had a cast-iron bevel wheel, which was considered the first introduced into Scotland, many years previous to the above date. Mr. Smeaton also had introduced iron wheels at Carron in 1754, and afterwards at a mill at Belper, in Derbyshire. (See Smiles's 'Life of Rennie,' page 138.)

Fig. 184.



The smoothness and economy of wheel-work depend entirely upon the accuracy of the curvature of the individual teeth which gear with one another. Two chief defects result from imperfections in their construction: first, the motion communicated to the driven wheel is irregular, increasing and diminishing alternately as each tooth passes the line of centres; and, second, there is an unnecessary friction between the teeth in gear, resulting not only in loss of power, but also causing a great and destructive wear in the teeth and journals. These defects can only be avoided by reducing, as far as practicable, the size of the teeth, and by the adoption of true principles in setting out their curvature in the original model.

To the first cause alone a large part of the perfect action of modern machinery of transmission is to be attributed; but there is moreover no doubt that, in practice, even where true principles have not been adopted, a considerable approach has been made to such forms as theory requires. Now, with certain limitations, it is known that if any form of tooth be taken for one wheel, there can be found another tooth which will work correctly with it. But there are certain forms which, being susceptible of accurate mathematical determination, are most convenient

for the purpose. Camus, in 1752, was the first to work out the properties of epicycloidal and hypocycloidal curves when employed in the construction of the teeth of spur and bevel gearing. De la Hire adopted the same form. Euler, in 1760, and Kaestner, in 1771, investigated in a similar manner the properties of the involute. Since their time, Ferguson, Buchanan, Hawkins, Rennie, and Airy, have all contributed to perfecting the mathematical theory. And Professor Willis, amongst other important additions, has shown how a close approximation to a true form may be made by the adoption of a system of circular arcs.

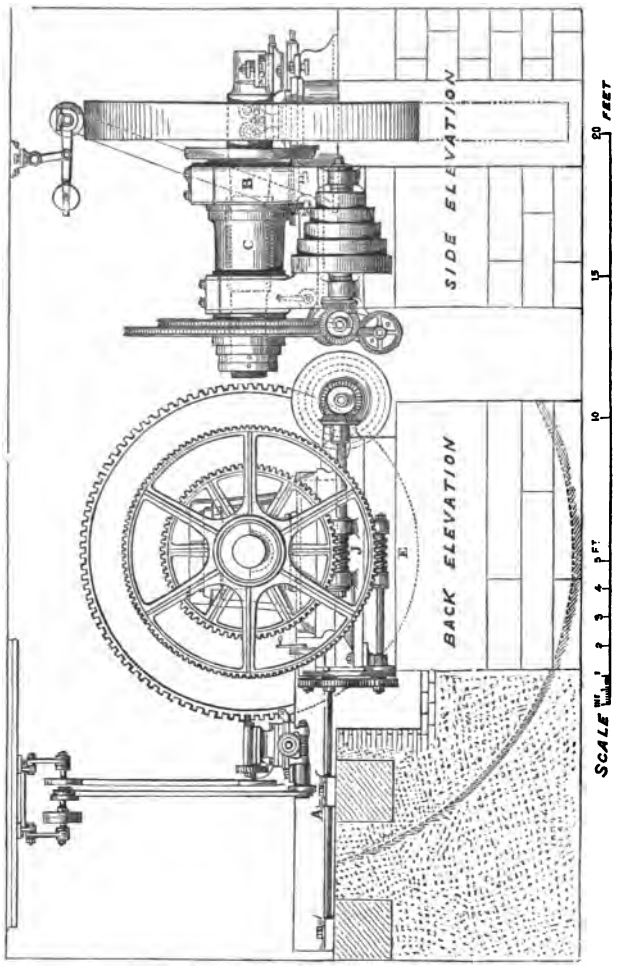
From 1788, when Rennie completed the Albion Mills, to the present time, wood and iron gear have been in general use for high velocities, and for every description of machinery where smoothness and accuracy of motion were required. Mr. Rennie was the first to introduce this system; and in most cases he made the driver, or large wheel, with wood cogs, and the driven, or pinion, of iron "chipped and turned"—that is, every tooth of the iron wheel was carefully divided in the pitch, having first been turned on the face and the ends of the teeth, and drawn to the epicycloidal form. They were then chipped with the hammer and chisel, and accurately filed to the required dimensions and forms. The same process was applied to the wooden teeth: and these wheels, when duly prepared, were keyed on their respective shafts, and securely fixed in contact at the mill.

The chipping and filing process has of late years been superseded by a cutting machine, which effects the same purpose, with less risk of error; and *the good old system of a penny an inch*, as practised in Rennie's time, has been exploded, much to the discomfiture of the old millwrights, who adhere with great tenacity to the hammer and chisel. Fig. 185 shows the cutting machine as constructed by Messrs. Peter Fairbairn and Co., of Leeds.

The object of this machine is not only to pitch and trim the teeth of a large spur or other wheel, but to turn the face and sides of the segments previously, when bolted to the arms.

When used as a lathe for turning, the parts in use are as follows: B is a large headstock, carrying a hollow spindle C,

Fig. 185.



through which is inserted a mandril upon which the wheel to be cut and turned is keyed. Provision is made for carrying the other end of this mandril by a loose fixing. The hollow spindle is driven (with the wheel upon it) by a worm wheel J which was made to run loose on a spindle, but which is now by a lock bolt connected to the larger worm wheel or dividing wheel E, the

worm of which is now thrown out, and keyed firmly on the spindle. The necessary speeds are given by the five-speed cone and mitre gear. The tool for turning is held in an ordinary slide rest, which moves transversely on a saddle, which slides and is fastened in the T grooves of two strong beds A, firmly secured to masonry, and between which the wheel revolves.

When used for pitching and trimming, the lock bolt connecting the two worm wheels is removed, and the pitch is given by the train of change wheels and division plate A. The place of the slide rest is now taken by a headstock carrying two cutters, one for roughing, and the other for finishing.

The finishing rose-cutter is the counterpart of the space between the teeth, and is traversed across, making both sides of the tooth alike.

The remainder of the arrangement will be obvious from the sketch. The same machine can also be readily arranged for cutting worm-wheel teeth, or for bevel gear.

The best form which can be given to the teeth of wheels is that which will cause them to be always, in regard to the power they mutually exert, in equally favourable situations, and, consequently, will give the machine the property of being moved uniformly by a power constantly equal. This would be accomplished by a simple rolling contact, which corresponds with the case in which the teeth are infinitely small.

Definitions.

1. Spur gearing is that in which the pitch lines of the driving and driven wheel are in the same plane (fig. 186).

Fig. 186.

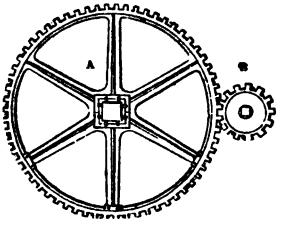
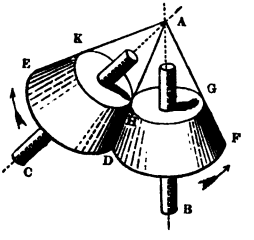


Fig. 187.



2. Bevel gearing is that in which the planes of the pitch lines of the driving and driven wheel are inclined to each other. In practice, they are in most cases at right angles (fig. 187).

3. Of two wheels in gear, the lesser is called the pinion.

4. When two wheels are in gear, a straight line joining their centres is called the line of centres.

5. If the line of centres be divided into two parts, proportionally to the number of teeth in the wheel and pinion, these parts are called the proportional or primitive radii of the wheel and pinion.

6. The radii of the circles which limit the extremities of the teeth are called the true radii.

7. If, from the centres of the wheel and pinion, circles be drawn with radii equal to the primitive radii, so that they touch one another in the line of centres, these circles are called the pitch lines of the wheel and pinion respectively.

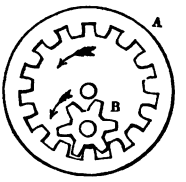
8. The acting surface of a tooth, projecting beyond the pitch circle, is called its face; that enclosed within the pitch circle, its flank.

9. The pitch of a wheel is the distance measured along the pitch circle from the face of one tooth to the corresponding face of the next; it includes, therefore, the breadth of a tooth and space. For two wheels to work in gear, the pitch must be the same in each.

10. Racks are toothed bars in which the pitch line is a straight line.

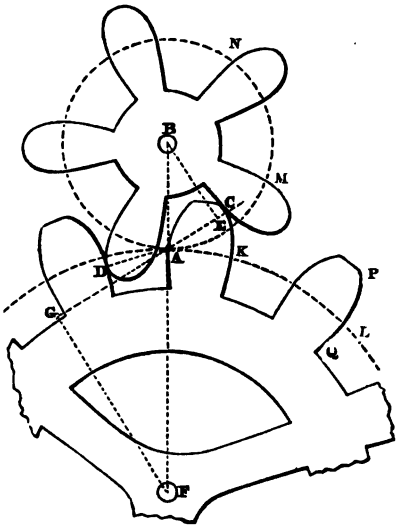
11. In annular wheels the teeth are cut on the internal edge of an annulus, or ring (fig. 188).

Fig. 188.



In fig. 189, B F is the line of centres; F A, A B, the primitive radii of the wheel and pinion respectively; A K L and A M N, the pitch lines; K L and M N, the pitch; P L, the face, and Q L, the flank, of the tooth.

Fig. 189.



The Pitch of Wheels.

We have seen that the pitch of a wheel is the length of an arc of the pitch line comprising a tooth and space. Millwrights ordinarily measure the pitch as a chord of this arc, and, except in pinions with very few teeth, the two measurements sensibly coincide.

Having the diameter of a wheel, and the number of teeth, the pitch may be found as follows:

Let D be the diameter of a wheel, N the number of teeth, and p the pitch; then, as 3·1416 D = the circumference of the circle,

$$p = \frac{3{\cdot}1416\ \text{D}}{\text{N}}$$

or approximately,

$$= \frac{22\ \text{D}}{7\ \text{N}}$$

Conversely, if the pitch of a wheel be given, and the number of teeth, then the diameter may be found,

$$\text{D} = \frac{p\ \text{N}}{3{\cdot}1416} = \frac{7\ \text{N}\ p}{22} \text{ nearly.}$$

And if the pitch and diameter of a wheel be given, then the number of teeth may be found,

$$N = \frac{3{\cdot}1416\ D}{p} = \frac{22\ D}{7\ p} \text{ nearly.}$$

But since a wheel must contain a whole number of teeth, N may never be a mixed number. If, therefore, this equation gives N with a fraction, a wheel cannot be constructed of that diameter and pitch. In this case, however, by slightly increasing or decreasing either the diameter or the pitch, the necessary conditions may be complied with.

In practice it is convenient to limit the number of pitches, with a view to the reduction of the number of patterns required for casting. Thus the following series gives all the most ordinary pitches of my own practice: —

Spur flywheels, 5, $4\frac{1}{2}$, 4, $3\frac{1}{2}$, $3\frac{1}{4}$, 3, $2\frac{1}{2}$, 2, $1\frac{1}{2}$ inches.

Spur and bevel wheels, 5, $4\frac{1}{2}$, 4, $3\frac{1}{2}$, $3\frac{1}{4}$, 3, $2\frac{3}{4}$, $2\frac{1}{2}$, $2\frac{1}{4}$, $2\frac{1}{8}$, 2, $1\frac{3}{4}$, $1\frac{5}{8}$, $1\frac{1}{2}$, $1\frac{3}{8}$, $1\frac{1}{4}$, $1\frac{1}{8}$, 1, $\frac{7}{8}$ inches.

Wheels of smaller pitch than these are not used in mill-work; but in machines, &c., the following pitches would probably be sufficient, viz.: —

1, $\frac{3}{4}$, $\frac{5}{8}$, $\frac{1}{2}$, $\frac{3}{8}$, $\frac{1}{4}$ inch.

The value of $\pi = \frac{22}{7}$ ordinarily employed is not very accurate; hence it is convenient to calculate beforehand the values of $\frac{p}{3{\cdot}1416}$ and $\frac{3{\cdot}1416}{p}$ for the most useful pitches.

The following table gives these values: —

Pitch in inches	$\frac{3{\cdot}1416}{\text{Pitch}}$	$\frac{\text{Pitch}}{3{\cdot}1416}$	Pitch in inches	$\frac{3{\cdot}1416}{\text{Pitch}}$	$\frac{\text{Pitch}}{3{\cdot}1416}$
5	0·6283	1·5915	$1\frac{3}{4}$	1·7952	0·5570
$4\frac{1}{2}$	0·6981	1·4270	$1\frac{5}{8}$	1·9264	0·5141
4	0·7854	1·2732	$1\frac{1}{2}$	2·0944	0·4774
$3\frac{1}{2}$	0·8976	1·1141	$1\frac{3}{8}$	2·2848	0·4377
$3\frac{1}{4}$	0·9666	1·0345	$1\frac{1}{4}$	2·5132	0·3978
3	1·0472	0·9548	$1\frac{1}{8}$	2·7924	0·3580
$2\frac{3}{4}$	1·1333	0·8754	1	3·1416	0·3182
$2\frac{1}{2}$	1·2566	0·7958	$\frac{7}{8}$	3·5904	0·2785
$2\frac{1}{4}$	1·3963	0·7135	$\frac{3}{4}$	4·1888	0·2386
2	1·5708	0·6366	$\frac{5}{8}$	5·0265	0·1988
$1\frac{7}{8}$	1·6755	0·5937	$\frac{1}{2}$	6·2832	0·1591

RULE 1.—Given the pitch and number of teeth in a wheel to find its diameter.

Multiply the number of teeth by the constant in the third or sixth column of the preceding table corresponding to the pitch.

RULE 2.—Given the pitch and diameter of a wheel to find the number of teeth.

Multiply the diameter by the constant in the second or fifth column of the table corresponding to the pitch.

If this rule gives a mixed number, or whole number and fraction, a wheel cannot be constructed, as before said. The most convenient way of proceeding in that case will be to take the nearest whole number to the number given by the rule, and, using Rule 1, find a new diameter which will differ but slightly from the one previously assumed. This new diameter must be taken for the pitch circle in constructing the wheel.

Thus, suppose it required to find the diameter of a wheel of 2 inches pitch and 150 teeth. By Rule 1, we have $D = 150 \times 0{\cdot}6366 = 95\frac{1}{2}$ inches = 7 ft. $11\frac{1}{2}$ inches.

Or, required the number of teeth in a wheel of 3 inches pitch and 9 feet diameter. By Rule 2: $N = 108 \times 1{\cdot}0472 = 113{\cdot}097$. Here the wheel will contain very nearly 113 teeth; but if we wish to know more accurately the diameter of a wheel of 3 inches pitch and 113 teeth, we find by the 1st Rule, $D = 113 \times 0{\cdot}9548 = 107{\cdot}89$ inches = 8 feet $11\frac{9}{10}$ inches. That is, a wheel of exactly 9 feet could not be constructed with a 3-inch pitch, but one of 8 feet $11\frac{9}{10}$ inches might and would contain 113 teeth.

Professor Willis has employed another method of graduating the sizes of wheels. Suppose the diameter, instead of the circumference, to be divided into as many equal parts as the wheel has teeth, and let one of these parts be called the diametral pitch of the wheel, to distinguish it from the common or circular pitch. Let M be the diametral pitch, so that

$$\frac{D}{N} = M$$

and let a series of values be taken for M in simple fractions of an inch, so that

$$M = \frac{1}{m}$$

where N and m are always whole numbers.

The ordinary values of m are 20, 16, 14, 12, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1, which include wheels in which the circular or common pitch varies from $\frac{1}{8}$ inch to 3 inches, as shown in the following table, given by Professor Willis: —

Value of m	Circular pitch in inches and decimals	Circular Pitch to nearest $\frac{1}{16}$th	Value of m	Circular Pitch in inches and decimals	Circular Pitch to nearest $\frac{1}{16}$th
3	1·047	1	9	·349	—
4	·785	$\frac{3}{4}$	10	·314	$\frac{5}{16}$
5	·628	$\frac{5}{8}$	12	·262	$\frac{1}{4}$
6	·524	$\frac{1}{2}$	14	·224	—
7	·449	$\frac{7}{16}$	16	·196	$\frac{3}{16}$
8	·393	$\frac{3}{8}$	20	·157	$\frac{1}{8}$

This system is convenient where wheels of small pitch are employed, and involves less calculation than the common system.

Since $\frac{D}{N} = M$, we have $M = \frac{p}{3{\cdot}1416}$; therefore, in the previous table (p. 14) the quantities in the third and sixth columns are the diametral pitches corresponding to the circular pitches in the first column, and the numbers in the second column are the corresponding values of m. In fact, this scheme differs from the first simply by expressing in small whole numbers the quantity $\frac{3{\cdot}1416}{p}$ instead of p.

The following table (pages 18 and 19) gives the relation of diameter, pitch, and number of teeth, for wheels of from $\frac{1}{2}$ inch to 5 inches pitch, and of from 12 to 200 teeth. Intermediate numbers may be found by direct proportion, by multiplying the number given for a wheel of half or a third of the number of teeth by two or three, or by adding together the diameters given for two wheels the sum of whose teeth is the number required. For an odd number of teeth, add the number given at the head of the table as many times as may be necessary to the diameter for a wheel of the nearest number of teeth given.

The Principles which Determine the Proper Form of the Teeth of Wheels.

The problem which presents itself in the construction of the teeth of wheels, is to discover the curvature which they should have in order that they shall revolve through the action of the teeth in precisely the same manner as they would by the rolling of the circumferences of their pitch lines.

The general principle by which this uniformity of motion is secured is as follows:—When wheels in gear act on each other so that a line perpendicular to the common tangent of the surfaces of the teeth at the point of contact passes always through the point where the pitch circles cut the line of centres, they will exert mutually the same force, move with uniform velocity, and be of true figure.

Or, in other words, the teeth will be rightly constructed when a line drawn from the point of contact of the pitch circles to the point of contact of two teeth is a normal to the surfaces in contact in all positions of the wheel and pinion.

Thus, let fig. 189 represent a wheel and pinion in gear, and let B A, A F be the primitive radii, and therefore A K L and A M N the pitch lines. Then if the teeth touch in C and D, and the lines A C, A D be always perpendicular to the common tangent to the touching parts, the teeth will be of true figure.

Epicycloidal Teeth.

The epicycloid is the curve traced by a fixed point in the circumference of a circle, which rolls over or within the circumference of another circle, or on a straight line. Thus, let the circle A B C (fig. 190, page 20) be fixed, and let the circle C D roll over its circumference, then a point C in the circumference of this the generating circle will describe an epicycloid C, C′, C″, C‴, C⁗, without the circle A B C. Similarly, a point F on the circumference of a generating circle F G, rolling within the circumference of A B C, will describe an interior epicycloid or hypocycloid F, F′, F″, F‴.

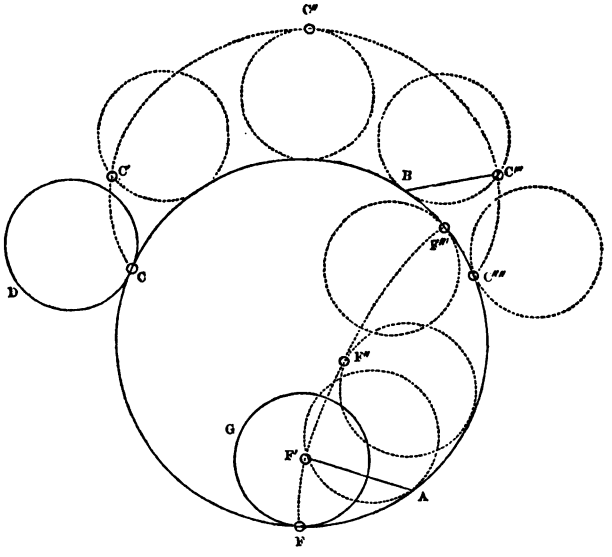
The remarkable properties of the epicycloid which determine its fitness for describing the teeth of wheels are: 1st, when the generating circle is half the diameter of the base circle, and

TABLE SHOWING THE RELATION OF PITCH, DIAMETER, AND NUMBER OF TEETH.

Number of teeth in wheel	Pitch in Inches														
	½	¾	1	1¼	1½	1¾	2	2¼	2½	2¾	3	3½	3½	4	4½	5
For each tooth add	·1591	·2386	·3182	·3978	·4774	·5570	·6366	·7135	·7958	·8754	·9584	1·035	1·114	1·273	1·427	1·592
12	1·91	2·86	3·82	4·77	5·73	6·68	7·64	8·56	9·55	10·50	11·46	12·41	13·37	15·28	17·12	19·10
13	2·07	3·10	4·14	5·17	6·21	7·24	8·28	9·28	10·35	11·38	12·41	13·45	14·48	16·55	18·55	20·69
14	2·23	3·34	4·46	5·57	6·68	7·80	8·91	9·99	11·14	12·26	13·37	14·48	15·60	17·83	19·98	22·28
15	2·39	3·58	4·77	5·97	7·16	8·36	9·55	10·70	11·94	13·13	14·32	15·52	16·71	19·10	21·41	23·87
16	2·55	3·82	5·09	6·37	7·64	8·91	10·19	11·41	12·73	14·01	15·28	16·55	17·83	20·37	22·83	25·46
17	2·70	4·06	5·41	6·77	8·12	9·47	10·82	12·13	13·53	14·88	16·23	17·59	18·94	21·64	24·26	27·06
18	2·86	4·30	5·73	7·17	8·60	10·03	11·46	12·84	14·32	15·76	17·19	18·62	20·05	22·92	25·69	28·65
19	3·02	4·54	6·05	7·56	9·08	10·58	12·10	13·56	15·12	16·63	18·14	19·66	21·17	24·19	27·11	30·24
20	3·18	4·77	6·36	7·96	9·55	11·14	12·73	14·27	15·92	17·51	19·10	20·69	22·28	25·46	28·54	31·83
21	3·34	5·01	6·68	8·36	10·02	11·70	13·37	14·98	16·71	18·38	20·05	21·72	23·40	26·74	29·97	33·42
22	3·50	5·25	7·00	8·76	10·50	12·25	14·01	15·70	17·51	19·26	21·01	22·76	24·51	28·01	31·39	35·01
23	3·66	5·49	7·32	9·16	10·98	12·81	14·64	16·41	18·30	20·13	21·96	23·79	25·62	29·28	32·82	36·60
24	3·82	5·73	7·64	9·55	11·46	13·37	15·28	17·12	19·10	21·01	22·92	24·83	26·74	30·56	34·25	38·20
25	3·97	5·97	7·96	9·96	11·94	13·93	15·92	17·84	19·90	21·89	23·87	25·86	27·85	31·84	35·68	39·79
30	4·77	7·16	9·55	11·93	14·32	16·71	19·10	21·41	23·87	26·26	28·64	31·04	33·42	38·21	42·81	47·74
35	5·57	8·35	11·14	13·92	16·71	19·50	22·28	24·97	27·85	30·64	33·42	36·21	38·99	44·57	49·95	55·70

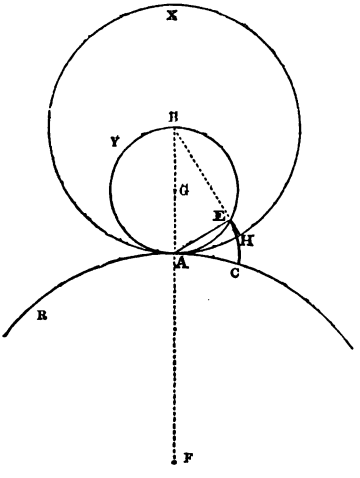
40	6·36	9·54	12·73	15·91	19·10	22·28	25·46	28·64	31·83	35·02	38·19	41·38	44·56	50·94	57·08	63·66
45	7 16	10·74	14·32	17·90	21·49	25·07	28·65	32·11	35·81	39·39	42·97	46·55	50·13	57·30	64·22	71·62
50	7·96	11·93	15·91	19·89	23·87	27·85	31·83	35·67	39·79	43·77	47·74	51·73	55·71	63·67	71·35	79·58
55	8·75	13·12	17·50	21·88	26·26	30·64	35·01	39·24	43·77	48·15	52·51	56·90	61·28	70·04	78·49	87·53
60	9·55	14·32	19·09	23·87	28·64	33·42	38·20	42·81	47·75	52·52	57·29	62·07	66·85	76·40	85·62	95·49
65	10·34	15·51	20·68	25·86	31·03	36·21	41·38	46·38	51·72	56·90	62·06	67·24	72·42	82·77	92·76	103·45
70	11·14	16 70	22 27	27·85	33·42	38·99	44·56	49·94	55·71	61·28	66·84	72·42	77·99	89·13	99·89	111·41
75	11·93	17·89	23·86	29·84	35·81	41·78	47·75	53·51	59·69	65·66	71·61	77·59	83·56	95·50	107·03	119·36
80	12·73	19·09	25·46	31·82	38·19	44·56	50·93	57·08	63·66	70·03	76·38	82·76	89·13	101·87	114·16	127·32
85	13·52	20·28	27 05	33·81	40·58	47·35	54·11	60·65	67·64	74·41	81·16	87·93	94·70	108·23	121·30	135·28
90	14·32	21·47	28·64	35·80	42·97	50·13	57·29	64·21	71·62	78·78	85·93	93·11	100·27	114·60	128·43	143·23
95	15·11	22·66	30·23	37·79	45·36	52·91	60·47	67·78	75·60	83·16	90·70	98·28	105·84	120·96	135·57	151·19
100	15·91	23·86	31·82	39·78	47·74	55·70	63·66	71·35	79·58	87·54	95·48	103·45	111·41	127·32	142·70	159·15
110	17·50	26·24	35·00	43·76	52·51	61·27	70·03	78·48	87·54	96·29	105·03	113·80	122·55	140·05	156·97	175·07
120	19·09	28·63	38·18	47·74	57·28	66·84	76·39	85·62	95·50	105·05	114·58	124·14	133 69	152·78	171·24	190·98
130	20·68	31·02	41·36	51·72	62·06	72·41	82·76	92·75	103·45	113·80	124·12	134·50	144·83	165·52	185·51	206·90
140	22·27	33·40	44·54	55·70	66·84	77·98	89·12	99·89	111·41	122·56	133·67	144·83	155·97	178·25	199·78	222·81
150	23·86	35·79	47·73	59·67	71·61	83·55	95·49	107·03	119·37	131·31	143·22	155·18	167·12	190·98	214·05	238·73
160	25·45	38·18	50·91	63 65	76·38	89·12	101·86	114·16	127·33	140·06	152·77	165·52	178·26	203·71	228·32	254·64
170	27·04	40·56	54·10	67·63	81·16	94·69	108·22	121·29	135 29	148·82	162·32	175·87	189·40	216·44	242·59	270·56
180	28·64	42·95	57·28	71·60	85·93	100·26	114·59	128·43	143·24	157·57	171·86	186·21	200·54	229·18	256·86	286·47
190	30·23	45·33	60·46	75·58	90·71	105·83	120·95	135·57	151·20	166·33	181·41	196·56	211·68	241·91	271·13	302·39
200	31·82	47·72	63·64	79·56	95·48	111·40	127·32	142·70	159·16	175·08	190·96	206·90	222·82	254·64	285·40	318·30

Fig. 190.



rolls within it, the hypocycloid is a straight line forming a diameter of the base; 2nd, if through the points of contact of the generating circle and the base, and the point describing the epicycloid, straight lines be drawn, these straight lines will be perpendicular to the curvature of the epicycloid at these points. Thus, for example, B C''' drawn from the point of contact B to the describing point C''', is a normal to the curve at that point; and similarly A F' is a normal to the curve at F'.

Fig. 191.



Suppose in the same plane three circles R X Y (fig. 191), which touch each other in the point A, and whose centres F B G are consequently in a straight line. Let one of these circles be made to revolve round its centre, and force the other two to turn round their

centres, which we suppose to be fixed, moving these circles by the point of continual contact A, common to the three circumferences; it is evident that all the parts of the circumference of the circle made to revolve will be applied in succession to every part of the circumferences of the other two circles, in the same manner as if the two circles R and X remained immovable, while the third, Y, revolved on the circumferences of the other two. Hence, if we suppose a style fixed to the circumference of the circle Y, movable round its centre, the three circles having been obliged to turn by the motion of the one which has carried along the other two; when the style is at E, if each of the two arcs A C and A H be made equal to the arc A E, the style will have described on the movable plane of the circle R, on the exterior part of which it revolves, a portion C E of an epicycloid, and on the movable plane of the circle X, within which we may consider it to revolve, a portion E H of a hypocycloid. (*Camus.*)

These two epicycloids traced out at the same time by the style E affixed to the circle Y, will touch each other in the point E; for the straight line A E drawn through A, where the generating circle Y touches its bases R and X, will be a normal to the two epicycloids. The same will be true in every position of the circles, viz. that the epicycloid and hypocycloid will have a common normal passing through A. Hence, if E C and E H be the faces of two teeth on the wheel and pinion R and X respectively, the condition of uniform motion already given will be complied with, the teeth will be of true form, and if the hypocycloid E H be moved by the epicycloid E C, or *vice versâ*, the wheel and pinion R and X will move precisely as if they rolled together at their pitch circles.

Wheels usually have their teeth constructed of such a form, that the flanks or parts within the pitch circle are bounded by straight lines radii of the pitch circles. Bearing in mind the property already stated, that the hypocycloid described by a generating circle of half the diameter of the base is a straight line forming a diameter of the base, we may so arrange our generating circle in describing the teeth of wheels as to comply with the above rule. By taking a generating circle Y of diameter equal to the radius of the base X, the hypocycloid E H

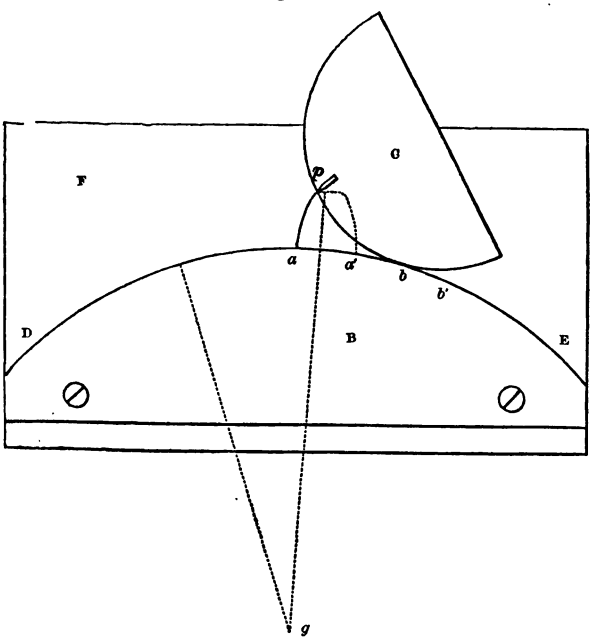
will be part of a radius of X; or, in other words, a radius B H of X will always touch the epicycloid C E described without the circle R, by a generating circle Y, of a diameter equal to the radius of X. And the angle B E A being the angle of a semicircle, will always be a right angle. That is, the perpendicular to the straight line B H, at the point of contact with the epicycloid E C, will always pass through A.

We have hitherto supposed the circles moved by contact at the point A, in order to explain the generation of the epicycloid C E and straight line E H; but if we suppose these already described, the former being fixed to the circle R, and the latter to the circle X; then if E H roll by contact on the epicycloid C E, it will move the circle R in precisely the same manner as if the circle were moved by contact at A.

Construction of Epicycloidal Teeth.

Since every tooth in a wheel is of precisely the same form, it is sufficient to construct a single pattern tooth of true epicy-

Fig. 192.

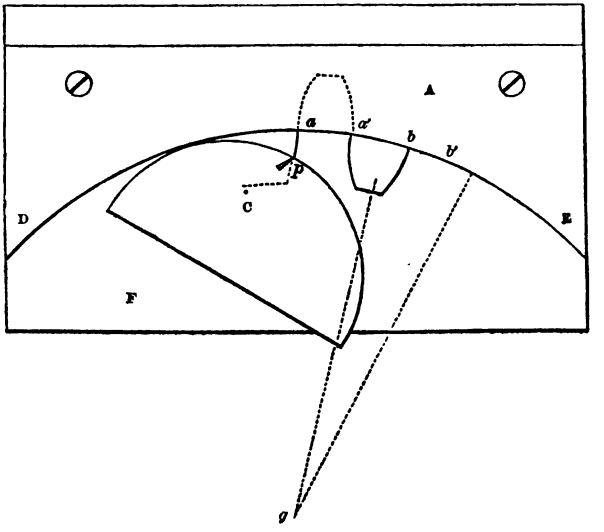


cloidal curvature, which may be used in setting out all the other teeth.

First method, when the generating circle is the same for wheel and pinion, the face of the tooth an epicycloid, and the flank a hypocycloid.

Construct two templets A and B (figs. 192, 193) having their faces arcs of the pitch circle of the wheel for which the tooth is required, and a third templet C cut to an arc of the intended generating circle of the epicycloid. Fix a steel tracing point p in the edge of the templet C, and for convenience a board F, on which to draw the tooth, may be fixed beneath the templet B. Mark off on the board F (fig. 192) the pitch circle of the wheel D E, and take distances $a\ b$, $b\ c$ equal to the pitch of the teeth, and distances $a\ a'$, $b\ b'$ equal to the thickness of the teeth. If then

Fig. 193.



the templet C be placed touching B, and with the tracing point p coinciding with one of the marks as a, and be rolled towards E, the point will trace out an epicycloid $a\ p$ on the board F, which will form one face of the tooth. Next let the point p be made to coincide with a', and the templet C be rolled towards D, the other face of the tooth will be described.

To draw the flanks, the templet A must now be fixed on the board F, with its face in contact with B; remove B and describe hypocycloids (fig. 193) from a and a', by rolling C on the inside of the pitch circle.

The length of the teeth is usually fixed as a proportional part of the pitch, but the least necessary length may be found experimentally by replacing the templet B on the board F, and making p coincide with a, roll C towards E till it touches B in b, the corresponding face of the next tooth; mark then the position of the tracing point, and through this point draw an arc from the centre g of the wheel: this arc will mark the extremity of the tooth, and the arc $g\,p$ will be the true radius of the wheel.

This process, which, though complicated in description, is very easy in practice, must be repeated with two templets cut to the pitch circle of the pinion, the same generating circle C being employed; a similar pattern tooth will thus be found for the pinion, which will work with that already found for the wheel. The usual custom in practice is for the millwright first to describe the epicycloidal and hypocycloidal forms of the teeth required in the wheel and pinion; he then constructs two model teeth, one for the wheel and the other for the pinion, and from these he determines the true curves, and by means of his compasses transfers the same to the wheels or patterns on which these forms are to be impressed. The generating circle, it may be observed, must not exceed in size the radius of the pinion, or it would give rise to a weak form of tooth, thinner at the root than at the pitch circle.

Second method, where two generating circles are employed, in order that the flanks of the teeth may be straight lines radii of the wheel and pinion respectively.

It is the usual practice of millwrights to make the parts of the teeth of wheels within the pitch circles radii of the wheel. Now, we have seen that a hypocycloid described by a generating circle equal in diameter to the radius of the wheel would be a diameter of the wheel. If, therefore, the flank of the tooth of the wheel and the face of the tooth of the pinion be described by a templet cut to a radius equal to half that of the wheel, and the flank of the tooth of the pinion and face of that of the

wheel be described by a templet cut to a radius equal to half that of the pinion, then these teeth will work together truly, and will have radial flanks.

Since it is unnecessary to describe the flanks of such teeth by templets, there will be needed only one templet cut to the pitch circle of each wheel, but templets of two generating circles are required. In other respects the method is identical with that already described. The great defect of this method is, that neither the wheel nor pinion will work accurately with a wheel or pinion of any other diameter than that for which they were originally made, and thus a vast number of wheel patterns must be made to fulfil the requirements of practice; whereas wheels described by the previous method will work equally well with all other wheels the teeth of which have been described by the same generating circle—it being understood that only the parts of teeth *without* the pitch circle of the wheel roll on the parts *within* the pitch circle of the pinion, and those without the pitch circle of the pinion on those within the pitch circle of the wheel.

Hence Professor Willis has been led to suggest that for a given set of wheels a constant generating circle should be taken to describe both the parts without and within the pitch circles of the whole series, instead of making that circle depend on the diameters of the wheels. In this case the first solution must be employed, and the flanks of the teeth will not be straight; but the great advantage is gained, that any pair of wheels in the series will work together equally well.

To determine the proper size of the generating circle, we must remember that a tooth of weak form is produced when the generating circle is greater than half the diameter of the wheel. Hence the generating circle may be best made of a diameter equal to the radius of the smallest pinion of the series which are to work together.

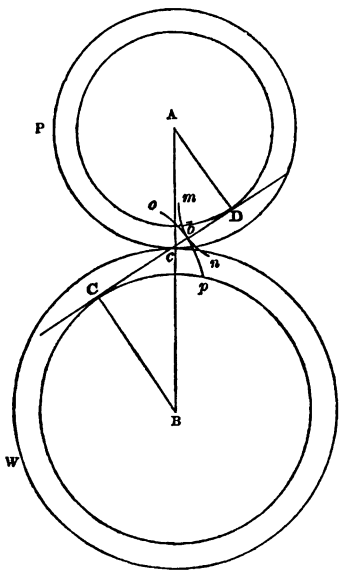
The Rack is the extreme case of a wheel, or may be considered as a wheel of infinite radius. It may be described by either of the methods above, only noting that, if the second method be employed, the generating circle which traces the face of the teeth of the wheel becomes a straight line, and the epicycloid becomes an involute.

If the teeth of a series of wheels and of a rack be described by the same generating circle, any of the wheels will work with equal accuracy into the rack.

Involute Teeth.

The Involute, the curve traced by a flexible line unwinding from the circumference of a circle, is called an involute.

Fig. 194.



Let P and W (fig. 194) be the pitch lines of a wheel and pinion, and let A and B be their centres. From A and B describe two circles D C, with radii A *b* and B *b* of the wheel and pinion respectively; so that

A C : B C :: A D : B C

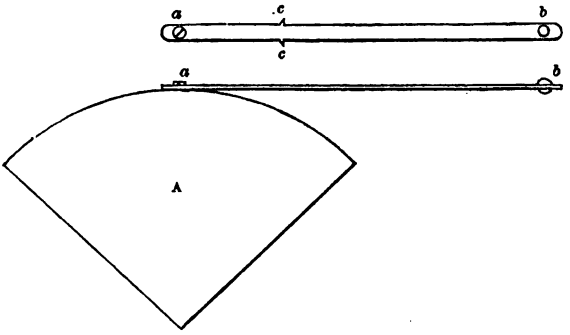
Let *m n* and *o p* be two involute curves described by flexible lines unrolling from the circles D and C respectively, and touching at *b*. Then if *b* C, *b* D be drawn tangents to the circles at the points D and C, they are also in one straight line, because they are both normals to the curves at *b*. It may also be shown that the line C D intersects A B in *c*, where the pitch lines touch. Hence we have found two curves such, that the line perpendicular to their common tangent passes in all positions of the wheel and pinion through *c*, which is the sufficient condition of their uniform motion, if moved by the sliding of the curves instead of by contact at *c*. Hence, if the wheels be constructed with teeth formed to these involute curves, they will work with perfect regularity of motion.

In practice, the chief condition to be observed is to diminish the pressure on the axes, which is the chief defect of this form of teeth. The common tangent should be drawn through *c*,

making an angle with A B, not deviating more than 20° from a right angle. Involute wheels have the double advantage that they work equally well if, through the wear of the brasses, the wheels have receded from one another; and any involute wheels of the same pitch and similarly described—that is, having the common tangent to the base circles passing through the point of contact of the pitch lines; or, in other words, base circles proportional to the primitive radii—will work together.

Mr. Hawkins, the translator of *Camus*, first proposed a simple instrument for describing the teeth of wheels to an involute curve. It consists of a straight piece of watch-spring *a b* (fig. 195), with a screw at one end, and filed away at the

Fig. 195.



edges so as to leave two teeth or tracers, *c c*, projecting from the edges of the watch-spring. At *b* a bit of wire is put through, and riveted, so as to form a knot by which the spring can be firmly held and stretched, as it is unwound from the base on which the involute is generated. This watch-spring is screwed to the edge of a templet A, curved to the radius of the base circle of the involute; and this being placed so that its centre coincides with the centre of the wheel, and revolved to bring one of the tracing points *c* in succession to each of the points at which corresponding faces of the teeth cut the pitch line, a series of involute curves may be described by unfolding the watch-spring, whilst keeping it firmly stretched tangentially to the sector to which it is fixed. The sector A must then be turned over, and the involutes of the opposite faces of the teeth struck in a similar manner.

Another plan is to employ a straight ruler instead of the watch-spring, a tracer being fixed in its edge. This shows that the involute is an epicycloid generated by a straight line. The ruler must be kept in contact with the base circle, and the tracer brought in succession to all the points in which the faces of the teeth cut the pitch line.

Hence, to describe a wheel with involute teeth, the line of centres must be drawn and divided proportionally to the number of teeth in the wheel and pinion. Draw the pitch line; divide the pitch line into the same number of equal parts as there are teeth in the wheel, and at these points mark out the thicknesses of the teeth all round. Draw the tangent to the base circles, making an angle of about 80° with the line of centres, which will give the radius of the base circle drawn touching it. A templet must be made to this radius, and then the involutes may be drawn by either of the preceding methods.

Allowance must be made to permit free play of the teeth in the spaces, the teeth being somewhat shorter than the distance between the bases of the involutes. But wheels of this figure require but little play in the engagement.

In the case of racks, the rack-teeth are bounded by straight lines perpendicular to the tangent drawn from the point where the pitch lines touch, to the base circle from which the involutes of the wheel are struck. If the teeth of the rack be made rectangular—that is, bounded by lines perpendicular to the pitch line—the involute must be struck from a base circle equal to the pitch circle of the wheel. In the former case there is a downward pressure on the rack; in the latter, the teeth of the wheel touch those of the rack in a single point—namely, the pitch line of the latter.

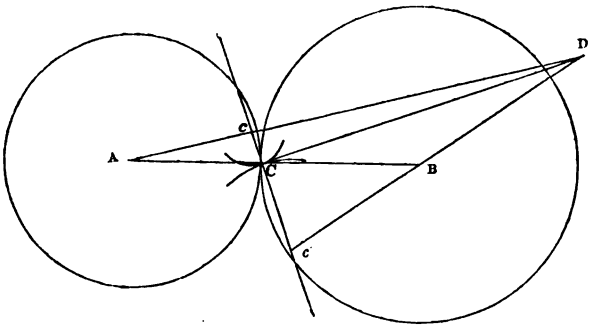
Professor Willis's Method of Striking the Teeth of Wheels.

In practice, the custom of describing the teeth of wheels as arcs of circles, has, from its simplicity, been generally adopted. The methods already given, however simple, when adopted in the formation of a single tooth, become tedious in their application to wheels of large size; and to this must be added the imperfect comprehension of their advantages by the millwrights charged with the task of designing wheel patterns.

Circular arcs struck at random, according to the judgment of the millwright, are often employed; and even where better principles have been introduced, it is common, after describing a single tooth accurately, to find by trial a circular arc nearly corresponding with its curve, and to employ this in marking out the cogs of the required wheel.

Seeing the advantages of the circular arc, and believing that it is not objectionable if only the employment of it is guided by true principles, Professor Willis has rendered this great service to practical mechanics—he has shown how, by a simple construction, the arcs of circles may be found, which, used in the construction of the teeth of wheels, will work truly on each other.

Fig. 196.



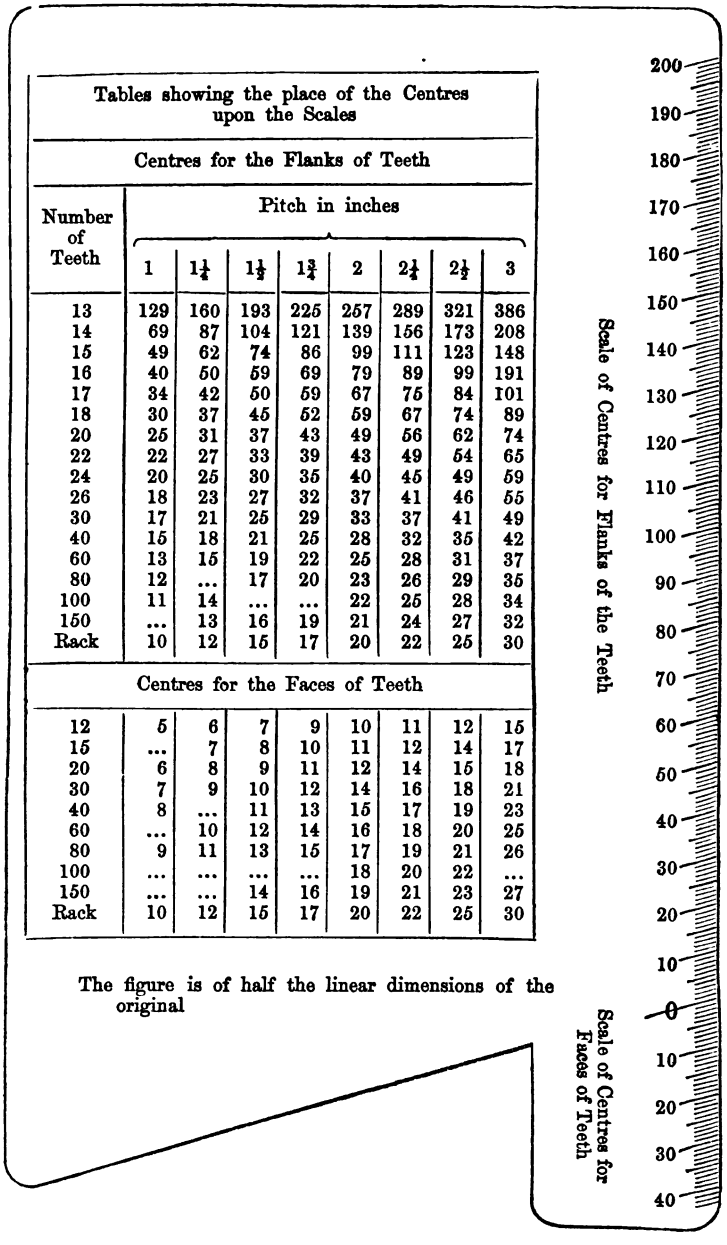
Let A B (fig. 196) be the centres of a wheel and pinion, and C the point of contact of the pitch circles on the line of centres. Through C draw c C c' at any angle with A B. Assume c as the centre from which to describe an arc for a tooth of the wheel A. Draw C D perpendicular to c C c', and from A through c draw A c D, meeting C D in D. Lastly, from D through B draw D B c', meeting c C c' in c'. Then a small arc drawn from c with radius c C as a tooth for the wheel A, will work correctly with a small arc drawn from c', with a radius c' C as a tooth for the wheel B.*

Professor Willis recommends 75° 30′ as the best magnitude of the angle A C c, so that Cos. 75° 30′ = $\frac{1}{4}$. If this angle be constant in a set of wheels, any two will work truly together.

For the easier description of these teeth, Professor Willis has

* Willis's 'Principles of Mechanism,' p. 123.

Fig. 197.



Tables showing the place of the Centres upon the Scales

Centres for the Flanks of Teeth

Number of Teeth	Pitch in inches							
	1	1¼	1½	1¾	2	2¼	2½	3
13	129	160	193	225	257	289	321	386
14	69	87	104	121	139	156	173	208
15	49	62	74	86	99	111	123	148
16	40	50	59	69	79	89	99	191
17	34	42	50	59	67	75	84	101
18	30	37	45	52	59	67	74	89
20	25	31	37	43	49	56	62	74
22	22	27	33	39	43	49	54	65
24	20	25	30	35	40	45	49	59
26	18	23	27	32	37	41	46	55
30	17	21	25	29	33	37	41	49
40	15	18	21	25	28	32	35	42
60	13	15	19	22	25	28	31	37
80	12	...	17	20	23	26	29	35
100	11	14	...	...	22	25	28	34
150	...	13	16	19	21	24	27	32
Rack	10	12	15	17	20	22	25	30

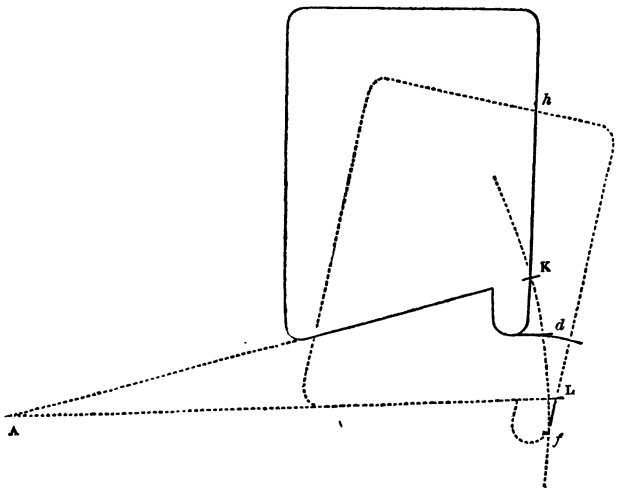
Centres for the Faces of Teeth

12	5	6	7	9	10	11	12	15
15	...	7	8	10	11	12	14	17
20	6	8	9	11	12	14	15	18
30	7	9	10	12	14	16	18	21
40	8	...	11	13	15	17	19	23
60	...	10	12	14	16	18	20	25
80	9	11	13	15	17	19	21	26
100	...	...	...	...	18	20	22	...
150	...	...	14	16	19	21	23	27
Rack	10	12	15	17	20	22	25	30

The figure is of half the linear dimensions of the original

invented the Odontograph, a simple instrument of graduated card or wood, by which the position of the centres and radii of the arcs of the teeth can very easily be found. This instrument* is of the form shown in fig. 197, of half its proper lineal dimensions. It has the bottom edge bevilled off at an angle of 75°. The point where this would cut the right-hand edge is the zero of the scales. These scales are graduated to twentieths of an inch, to avoid fractional parts in the tables, and depart in each direction from the zero, the upper being that employed in finding the centres of the flanks of the teeth or parts within the pitch circle, and the lower for finding the centres of the faces of the teeth or parts without the pitch circle. Tables are given on the odontograph for finding the graduation on the scale corresponding to any given pitch and number of teeth. For intermediate pitches, not given in the table, or for wheels of greater size, the corresponding numbers can be found by simple proportion. For wheels of only twelve teeth the flanks are straight, and form parts of radii of the pitch circle.

Fig. 198.



In fig. 198, let A be the centre of a wheel, K *d* L the pitch line. Set off K L equal to the pitch, and bisect it in *d*. Draw

* Professor Willis's Odontograph may be obtained of Messrs. Holtzapfel of London.

radii A K, A L. Place the odontograph with its bevilled edge on the radius A K, and zero of the scale on the pitch line. Then look out in the table of centres for the flanks of teeth, the number corresponding to the pitch, and required number of teeth, and mark off this point *h* from the scale of centres for the flanks of teeth. Then remove the odontograph, and similarly place it on the radius A L. Find in the table of centres for the faces of the teeth the number corresponding to the pitch and number of teeth in the wheel, and mark it off at *f*, on the scale for centres of the faces of teeth. Then describe two arcs from *h* and *f*, with *h d* and *f d* as radii; these will form the side of a tooth. Then, from *d* let the pitch line be marked off into as many equal spaces as there are teeth in the wheel, and these be divided proportionally to the widths of the teeth and spaces. Through *h* and *f*, with radii A *h* and A *f*, draw circles. Take *h d* as a radius, and, placing one foot of the compass on the divisions of the pitch line, and the other in the circle drawn through *h*, describe a series of arcs forming the flanks of the teeth. Similary with radius *f d*, and one leg of the compass on the circle drawn through *f*, describe the faces of the teeth.

For an annular wheel the same rules apply, only that the part of the curve which is face in a spur wheel becomes the flank in an annular wheel, and *vice versâ*. For a rack, the pitch line is straight, and A K, A L are parallel and perpendicular to it, at a distance equal to the pitch.

As these odontographs may be purchased in a very convenient form, with tables for their use, and also with tables of the widths of teeth, and spaces and length of teeth within and without the pitch circle, it is not necessary to describe them in further detail here.

General Form and Proportions of Teeth of Wheels.

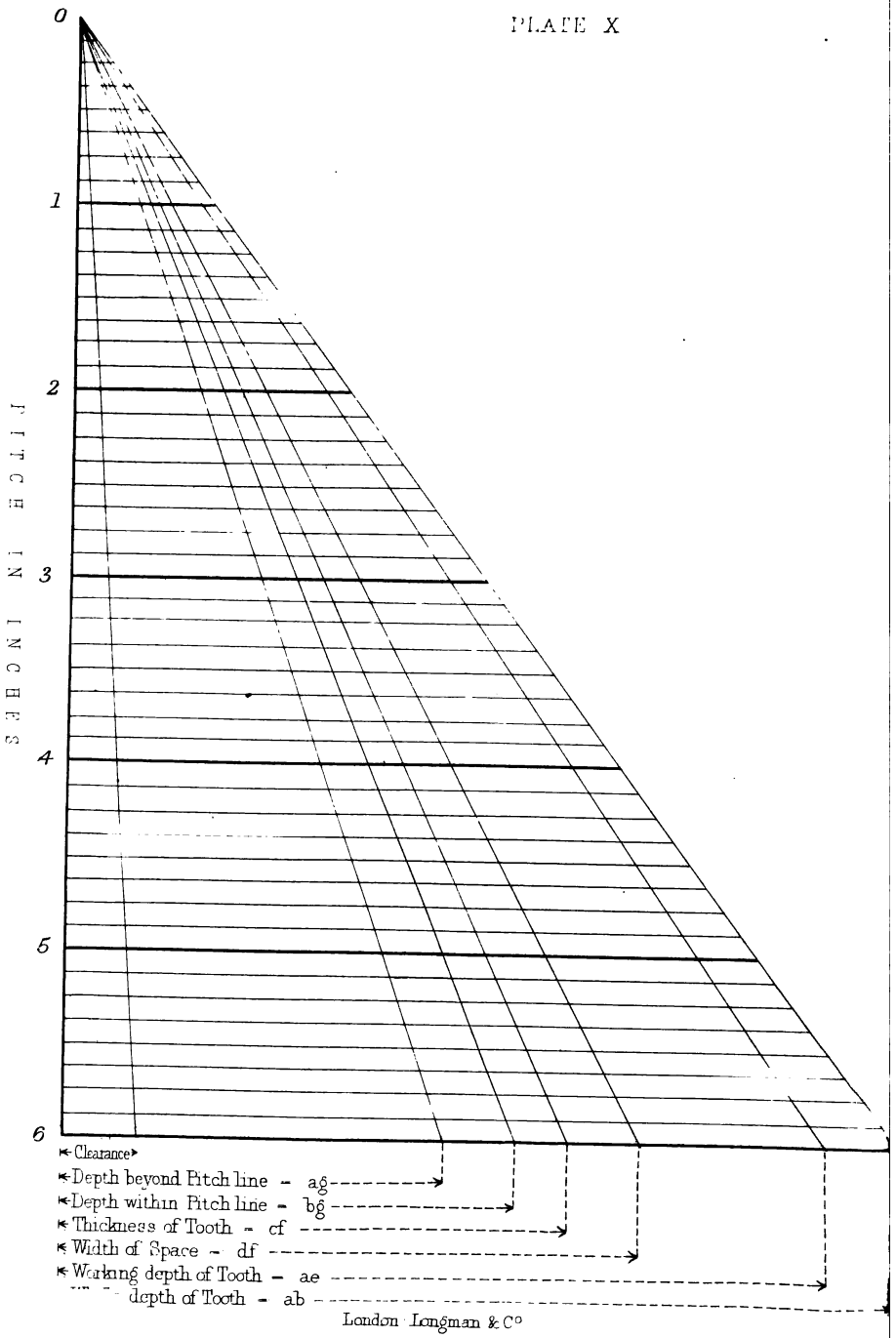
On Plate IX. have been drawn a series of wheels and racks to illustrate the general form of the teeth of wheels. The pitch in figs. 1, 2, 3, and 4 is one inch, and that in fig. 5 is 2½ inches.

In figs. 1, 2, 3, and 4, the wheel is 19·1 inches diameter; in fig. 5 it is 13 feet diameter.

Fig. 1 represents the form of the teeth on Professor Willis's system, the curves being arcs of circles. Fig. 2 gives the form

TH

PLATE X



London Longman & Co

of epicycloidal teeth, struck by a single generating circle rolled without the pitch circle for the faces, and within it for the flanks. This is the best system, as any pair of wheels so struck, with the same generating circle and of equal pitch, will work together. Fig. 3 shows the common form of epicycloidal teeth, the flanks being straight. In this case the faces of the rack are struck by a generating circle half the diameter of the wheel, and the faces of the wheel, being obtained by a generating circle of infinite diameter or straight line, become involutes. Fig. 4 gives the form of teeth described as involutes, the curve being continuous, and, in the case of the rack, a straight line perpendicular to the tangent to the base circle. In these teeth it is possible to work with very little play. They are a good form for wheel and rack working together, the pressure on the journals being in this case less objectionable. Fig. 5 shows the teeth of a large wheel, traced from one of my own patterns, to exhibit the form and proportion which practice has shown to be desirable.

In these teeth the pitch $c\ d$ being $2\frac{1}{2}$ inches, the depth of the tooth or distance $a\ b$ is $\frac{5}{8}$ths or $\frac{3}{4}$ths of the pitch. The proportions of the parts may be given as follows: —

				Proportional part		Inches
Pitch	=	$c\ d$	=	1·00	=	$2\frac{1}{2}$
Depth	=	$a\ b$	=	0·75	=	$1\frac{7}{8}$
Working depth	=	$a\ e$	=	0·70	=	$1\frac{3}{4}$
Clearance	=	$e\ b$	=	0·05	=	$\frac{1}{8}$
Thickness	=	$c\ f$	=	0·45	=	$1\frac{1}{8}$
Width of space	=	$f\ d$	=	0·55	=	$1\frac{3}{8}$
Play or $f\ d$, $c\ f$	=		=	0·10	=	$\frac{1}{4}$
Length beyond pitch line	=	$a\ g$	=	0·35	=	$\frac{7}{8}$

Taking these proportions, we may construct a scale which shall give directly the corresponding numbers for any pitch. Taking a vertical line, and dividing it into eighths of an inch, we get the scale of pitches (Plate X.). Draw lines perpendicular to this, and on any one of them mark off a series of distances equal to the clearance, depth, thickness, &c., of the teeth corresponding to that pitch. Through o and these points draw the lines shown in the figure; they will divide the lines corresponding to all other pitches in the same proportion.

It is usual to allow a greater amount of clearance in small

wheels than is necessary in large ones. Very varying proportions have been given by different millwrights, $\frac{1}{10}$th, $\frac{1}{12}$th, $\frac{1}{15}$th, and $\frac{1}{20}$th of the pitch having been used in different circumstances, even with the best mill-work. In the scale (Plate X.) this has to a certain extent been taken into account; $\frac{1}{10}$th of the pitch is allowed in smaller wheels, decreasing to $\frac{1}{15}$th in the largest; hence the lines are not absolutely straight, but are slightly curved, except that for the whole depth of the tooth, which quantity has been assumed to vary directly as the pitch.

Assuming that this scale represents with sufficient accuracy the proportions which practice shows to be best in average cases, we may construct a table for the guidance of the millwright. From this he must vary in cases where it appears necessary to allow more for defects of workmanship, or to permit less "backlash;"* it being understood that the table will only apply in cases where the teeth are formed with an approximation to the true mathematical figure.

In wood and iron gear where the teeth are carefully cut, very little if any clearance is necessary, as they work much better when the tooth of each wheel fills their allotted spaces. It is,

TABLES OF PROPORTIONS OF TEETH OF WHEELS FOR AVERAGE PRACTICE.

Pitch	Clearance and play	Depth beyond pitch line	Depth within pitch line	Working depth	Whole depth	Thickness of tooth	Width of space
$\frac{1}{2}$	·06	·16	·22	·32	·38	·22	·28
$\frac{3}{4}$	·08	·25	·33	·50	·58	·33	·42
1	·10	·335	·435	·67	·77	·45	·55
$1\frac{1}{4}$	·12	·42	·54	·84	·96	·56	·69
$1\frac{1}{2}$	·13	·51	·64	1·02	1·15	·68	·82
$1\frac{3}{4}$	·14	·60	·74	1·20	1·34	·80	·95
2	·16	·685	·845	1·37	1·53	·92	1·08
$2\frac{1}{4}$	·17	·775	·945	1·55	1·72	1·04	1·21
$2\frac{1}{2}$	·19	·86	1·05	1·72	1·91	1·15	1·35
$2\frac{3}{4}$	·20	·95	1·15	1·90	2·10	1·27	1·47
3	·22	1·04	1·26	2·08	2·30	1·39	1·61
$3\frac{1}{4}$	·23	1·13	1·36	2·26	2·49	1·51	1·74
$3\frac{1}{2}$	·25	1·215	1·465	2·43	2·68	1·62	1·88
$3\frac{3}{4}$	·26	1·305	1·565	2·61	2·87	1·74	2·01
4	·28	1·39	1·67	2·78	3·06	1·86	2·14
$4\frac{1}{2}$	·31	1·565	1·875	3·13	3·44	2·09	2·40
5	·34	1·745	2·085	3·49	3·83	2·33	2·67
$5\frac{1}{2}$	·37	1·925	2·295	3·85	4·21	2·56	2·93
6	·40	2·10	2·50	4·20	4·60	2·80	3·20

* A technical expression for *reaction* on the back of the teeth.

however, different where wheels have to gear together direct from the foundry, where the teeth are not unfrequently deranged in the act of moulding in the sand.

This table gives the number to the nearest hundredth of an inch. It may be converted into the ordinary scale of eighths by the following table:—

	Thirty Seconds of an Inch									
	1	2	3	4	5	6	7	8	9	10
Corresponding Decimal	·031	·062	·094	·125	·156	·188	·219	·250	·281	·3125

As, unfortunately, decimal scales are not yet much used by millwrights, the following table has been prepared, giving the numbers in the preceding table in thirty-seconds of an inch, such changes being made as will reduce as much as possible the errors of employing this rough standard. The former table is to be preferred where it can be used, but in other cases the following one may be relied on. The left-hand figures in each

TABLE GIVING THE PROPORTIONS OF THE TEETH OF WHEELS IN INCHES AND THIRTY SECONDS OF AN INCH.

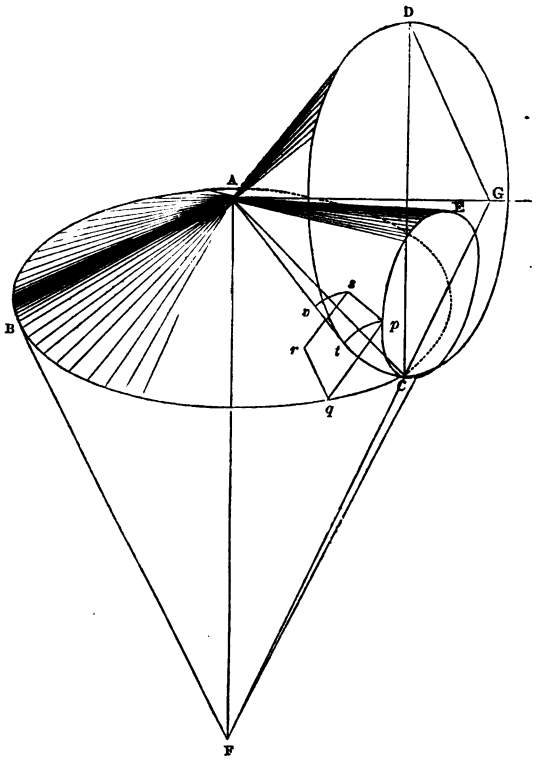
Pitch, inches	Clearance	Depth beyond the pitch line	Depth within the pitch line	Working depth	Whole depth	Thickness of tooth
¾	0″ 2	0″ 5	0″ 7	0″ 10	0″ 12	0″ 7
¾	0 3	0 8	0 11	0 16	0 19	0 10
1	0 3	0 11	0 14	0 22	0 25	0 14
1¼	0 4	0 13	0 17	0 26	0 30	0 18
1½	0 4	0 16	0 20	1 0	1 4	0 21
1¾	0 4	0 19	0 23	1 6	1 10	0 25
2	0 5	0 22	0 27	1 12	1 17	0 29
2¼	0 5	0 25	0 30	1 18	1 23	1 1
2½	0 5	0 28	0 33	1 24	1 29	1 5
2¾	0 6	0 31	0 37	1 30	2 4	1 8
3	0 7	1 1	1 8	2 2	2 9	1 12
3¼	0 7	1 4	1 11	2 8	2 15	1 16
3½	0 8	1 7	1 15	2 14	2 22	1 20
3¾	0 8	1 10	1 18	2 20	2 28	1 23
4	0 9	1 12	1 21	2 24	3 1	1 27
4½	0 10	1 18	1 28	3 4	3 14	2 3
5	0 11	1 24	1 35	3 16	3 27	2 10
5½	0 11	1 30	1 41	3 28	4 7	2 18
6	0 12	2 4	2 16	4 8	4 20	2 25

column are inches, the right-hand ones thirty seconds of an inch, the denominators of the fraction being omitted.

Bevel Wheels.

Hitherto we have considered only that case of toothed wheels in which the pitch lines are in one plane. We have now to examine the modifications which are necessary when the axes of

Fig. 199.



the wheel and pinion are inclined. It was shown in the preliminary Chapter* that in this case motion might be transmitted by the rolling contact of the frustra of two cones. If, therefore,

* Mills and Mill-work, Vol. I., p. 46, §§ 68, 69.

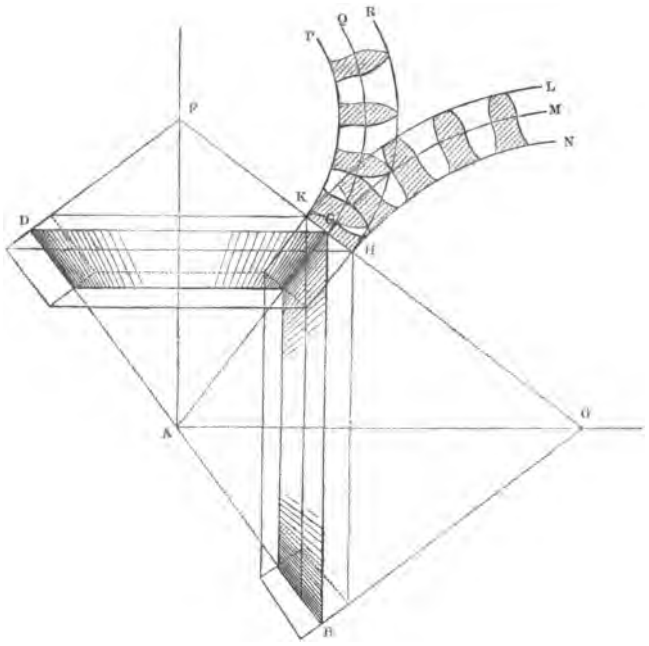
teeth be applied to these frustra, in the same manner as in spur gearing they are attached to cylindrical surfaces, bevel gearing will be formed acting on the same principles of sliding contact which we have already discussed.

Let A B C, A C D (fig. 199) be two cones rolling in contact; take any other cone A E C also rolling in contact with A B C, in the line A C. As these cones roll together, the generating cone A E C will describe an epicycloidal surface *p q r s* on the outside of the cone A C D, and a hypocycloidal surface *p t v s* on the inside of the cone A C D. These surfaces will touch in the line *p s*, and will have a plane normal to their common tangent passing through A C. If, therefore, these surfaces be attached respectively to the cones A B C, A C D, and the motion of one cone be communicated to the other through the sliding contact of these surfaces, the motion will be uniform, as if the cones were driven by rolling contact at A C.

The curves *p t*, *p q*, lie in reality on the surface of a sphere of a radius equal to A C; but in practice, in bevel wheels, a small frustrum of a cone, tangential to the sphere at the circumference of the pitch line, is substituted for the spherical segment. Thus draw F C G (fig. 199) perpendicular to A C, cutting the axes of the cones in F and G. Let these lines revolve over the pitch lines of the cones and describe the narrow frustra. Then the epicycloidal surfaces may, without sensible error, be supposed to lie in these frustra, and to be generated there by the revolution of a generating circle C E.

Imagine the surface of these frustra to be unwrapped so as to lie in one plane; they will form parts of circular annuli. Thus let A B C, A C D (fig. 200) be two conical frustra; draw F C G as before, perpendicular to the line of contact A C. From G, with radii G H, G C, and G K, describe the circles K L, C M, H N; and from F, with radii F K, F C, F H, describe similar circles K P, C Q, H R; then the surfaces K P R H and K L N H will be developements of the frustra C D, C B. Let these be treated as spur wheels, and C Q, C M being treated as the pitch lines, let teeth be described by a describing circle in the method already explained for epicycloidal or other teeth. If, then, the plane on which these have been described, and which we suppose of drawing paper or other flexible material, be cut along the arcs K P, H R, K L, H N,

Fig. 200.



the circular annuli may be wrapped round the frustra C B, C D, and the forms of the teeth traced off upon them.

The axes of bevel wheels are in practice, in the great generality of cases, at right angles. Fig. 200 shows such a pair of bevels, with the frustra of the extremity of the teeth developed in the manner described.

Skew Bevels.

When two axes or shafts, which have to be connected by bevel wheels, do not meet in direction, it is usual, as stated in the preliminary Chapter,* to introduce an intermediate bevel wheel with two frustra. But the same object can more easily be accomplished by adopting skew bevels.

Let B p q (fig. 201) be the place of one of the two frustra, a its centre, and a e the shortest distance between the axis of

* Mills and Mill-work, Vol. I., p. 47, §§ 70, 71.

Fig. 201.

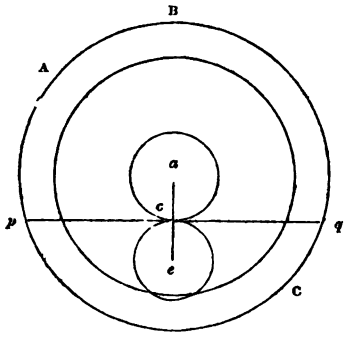
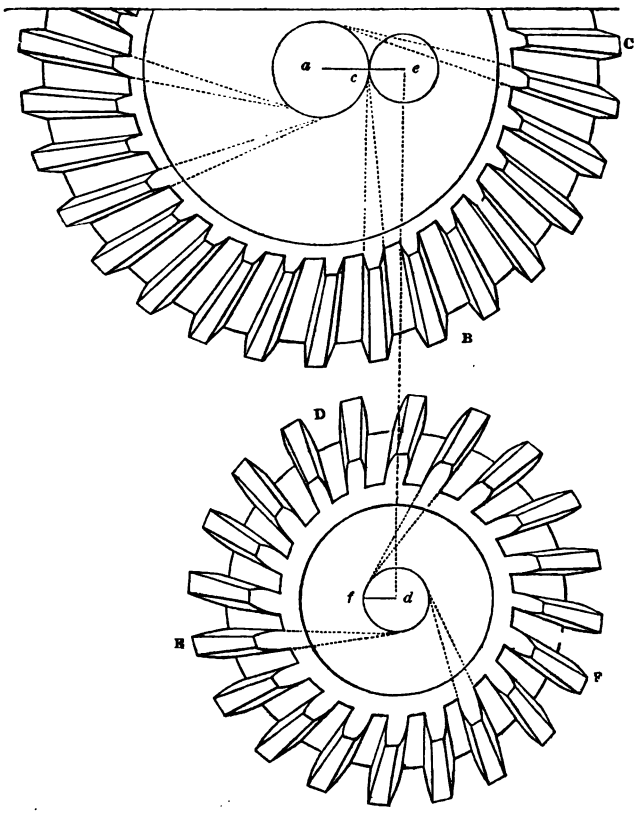


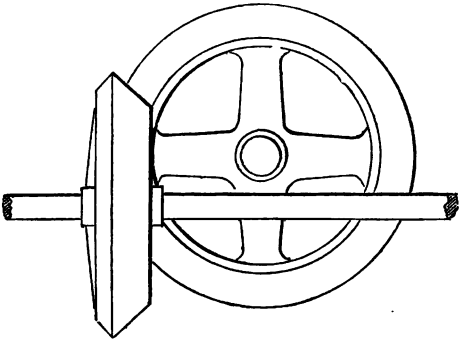
Fig. 202.



B p q, and the axis of the wheel to be connected with it. Divide a e in c, so that $a c$: $e c$ :: mean radius of A B C : mean radius of frustrum working with A B C. Draw c p q perpendicular to $a e$; then $c p$ or $c q$ is the line of action of the teeth, according to the direction in which the teeth are laid out in the pinion.

Figure 202 shows two wheels laid out in this manner; $a e$, as before, is the eccentricity or shortest distance between the two shafts, and is divided in c proportionally to the mean radii of the wheels; with centre a and radius $a c$ describe a circle, and draw $e d$ perpendicular to $a e$. Take $d f = c e$; then d will be the centre of the other wheel. From centre d, with radius $f d$, describe a circle. Then the directions of all the teeth in A B C will be tangents to the circle described about a, and the directions of all the teeth in D E F will be tangents to the circle described about f. Fig. 203 shows two such wheels in gear, the eccentricity permitting the shafts to pass each other.

Fig. 203.

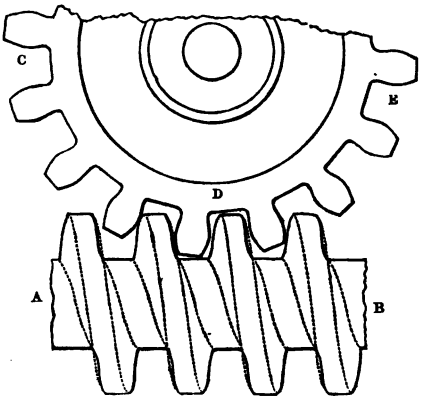


The Worm and Wheel.

By this contrivance the motion of a screw is communicated with great smoothness to oblique teeth on a spur wheel.

The section of a screw through its axis is precisely similar to that of a double rack. Let A B be such a section, and for simplicity suppose that the form of the threads of the screw has been determined by one of the rules already given for racks.

Fig. 204.



Then the teeth of the wheel C D E may evidently be formed so as to work with the centre section of the screw. Now the effect of the revolution of the screw is precisely similar to that of the racks, and the sections of the threads of the screw will appear to travel from end to end, in the same way as a rack pushed forwards in the same direction. If, therefore, it is sufficient that the wheel teeth be in contact with the screw at one point only, the teeth of the wheel may be made oblique, but straight, the obliquity being equal to the pitch of the screw. This is the usual practice of millwrights. If, however, the teeth are required to be in contact with the entire breadth of the tooth, the outline of the tooth must vary in every section of the wheel, and the process of describing these teeth becomes very complex. Practically, the difficulty has been overcome by first making a pattern screw of steel, notched in the threads to convert it into a cutting instrument. The wheel is then roughly cut out, and, being fixed in a frame, the screw is used to cut out the spaces between the teeth to their true form.

Strength of the Teeth of Wheels.

The pressure on the teeth varies directly as the horse-power transmitted, and inversely as the velocity of revolution. Thus if one wheel transmit 5 horse-power and another 10 horse-

power at the same velocity, the strain on the latter will be twice that on the former. Or, again, if two wheels transmit the same power, but one at a velocity of 100 feet per minute, and the other at only 25 feet per minute, the strain on the former will be only one-fourth that on the latter.

Let v be the velocity in feet per second, H the number of horse-power transmitted; then the total pressure on the wheels will be—

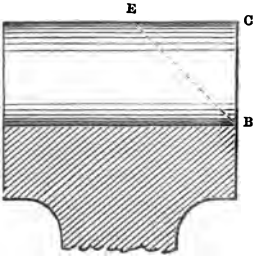
$$P = \frac{550\,H}{v}$$

where P is the statical pressure in lbs.

For example, suppose the fly-wheel of an engine to be 24 feet in diameter, and to work into a pinion 5 feet diameter. And let the work transmitted be 150 horse-power. Then, if the wheel makes 25 revolutions per minute, the periphery will move at a velocity of $\frac{75{\cdot}4 \times 25}{60} = 31{\cdot}4$ feet per second; and the statical pressure on the teeth will be $\frac{550 \times 150}{31{\cdot}4} =$ 2,627 lbs.

In addition to statical pressure, however, a different element has to be taken into account, namely, the impacts due to sudden accelerations or retardations of speed. The allowance which must be made to prevent accident from this cause varies exceedingly in different kinds of machinery. It is great in the gearing of rolling mills for instance, and in all machinery in which the strains are irregular.

Fig. 205.



In calculating the strength of the tooth, it has been usual to consider it as a short beam fixed at one end, and having the whole of the pressure applied along the extremity of the tooth. But there is a position in which the teeth may be subjected to a severer stress still; owing to the wear of brasses and teeth, we cannot calculate upon the strain bearing always on the whole breadth of the tooth. The pressure may not only come on to the extremity of a tooth,

but, if any obstruction come in between the teeth, it may be thrown entirely upon one corner of the tooth. In such a case it may be shown, by the rules of maxima and minima, that if E C = C B the greatest stress will be near the line E B.

Tredgold has expressed the strength of a tooth on this supposition by the formula

$$W = \frac{f d^2}{5}$$

where d is the thickness of the tooth. To allow for wear, however, he adds one-third, so that

$$W = \frac{f d^2 (1 - \frac{1}{3})^2}{5} = \frac{f d^2}{10{\cdot}25}$$

In cast iron $f = 15{,}300$, and hence

$$d = \sqrt[2]{\frac{W}{1500}}$$

Or, in words, the thickness necessary for the tooth or inches is equal to the square root of the stress on the tooth in pounds divided by 1,500. Hence Tredgold has computed the following table, the breadths of the teeth being deduced, on the principle that the stress should not exceed 400 lbs. per inch breadth :—

TABLE OF THICKNESS, BREADTH AND PITCH OF TEETH OF WHEELS.

Stress in lbs. at the pitch line	Thickness of teeth in inches	Breadth of teeth in inches	Pitch in inches
400	0·52	1	1·1
800	0·73	2	1·5
1,200	0·90	3	1·9
1,600	1·03	4	2·2
2,000	1·15	5	2·4
2,400	1·26	6	2·7
2,800	1·36	7	2·9
3,200	1·46	8	3·0
3,600	1·56	9	3·3
4,000	1·64	10	3·4
4,400	1·70	11	3·6
4,800	1·78	12	3·7
5,200	1·86	13	3·9
5,600	1·93	14	4·0
6,000	2·00	15	4·2

To use this table when the horses' power transmitted by the wheel are known, the reader must refer to the table on page 47.

Elsewhere Tredgold has given a rule of the following description:—

$$d = \tfrac{3}{4}\sqrt{\frac{\text{H}}{v}} \text{ for cast iron,}$$

where d is the requisite thickness of a tooth to transmit a force of H horses at a velocity v feet per second.

Hence Tredgold's last rule for the thickness of cast-iron teeth is as follows:—"Find the number of horses' power transmitted by the wheel, and divide that number by the velocity in feet per second of the pitch line of the pinion or wheel; extract the square root of the quotient, and three-fourths of this root will be the least thickness of cast-iron teeth for the wheel or pinion." From this he derives a second rule for the pitch, which manifestly depends on the thickness of the tooth; namely, multiply the thickness of the tooth by 2·1, and the product will be the pitch. The same result may be obtained by inspection from the tables I have given at pages 34, 35. Wooden teeth he recommends to be made of twice the thickness of cast iron ones. But one and a half times the thickness is a sufficient allowance.

A writer in the "Engineer and Machinists' Assistant" deduces another but equally simple rule for the thickness of teeth; he assumes the relation

$$t = c\sqrt{\text{W}};$$

where t is the thickness of the tooth W, the pressure on the tooth and c a constant depending on the nature of the material. Let then a be the strength of a bar 1 inch long, 1 broad, and 1 thick. Then, to support a weight W by a bar of a length l, and breadth b,

$$t = \sqrt{\frac{\text{W} \times l}{a \times b}};$$

suppose the breadth of the tooth to be fixed at twice its length;

$$t = \sqrt{\frac{\text{W}\, l}{a + 2\, l}} = \sqrt{\frac{\text{W}}{2\, a}}.$$

Taking $a = 8{,}000$ lbs. for cast iron, $2a = 16{,}000$ lbs., but as this is the breaking-weight, the safe working-pressure will be only 1,600 lbs., and the thickness of the tooth for safe working will be for cast iron:

$$t = \sqrt{\frac{w}{1600}} = 0{\cdot}025\sqrt{w}.$$

Where w being given in lbs. t is found in inches. Similarly for other materials he obtains:

$$c = {\cdot}035 \text{ for brass,}$$
$$= {\cdot}038 \text{ for hard wood.}$$

For example, in the wheel assumed at p. 41, w was found to be 2,627 lbs. Hence the necessary thickness of the tooth, if of cast iron, would be $\cdot025\sqrt{2627} = 1{\cdot}28$ inches. Referring to the tables of the relation of pitch, &c., we find that the wheel must be of $2\frac{3}{4}$ inches pitch, the teeth of 2·1 inches length, and the breadth of the wheel $2{\cdot}1 \times 2 = 4{\cdot}2$ inches at the least. By Tredgold's latter rule, the thickness of the teeth for the same wheel would be $t = \frac{3}{4}\sqrt{\frac{150}{31{\cdot}4}} = 1{\cdot}41$ inches; the pitch $= 2{\cdot}1 \times 1{\cdot}41 = 3{\cdot}0$ inches, and the breadth $= \frac{2627}{400} = 6\frac{1}{2}$ inches.

Bearing in mind that $w = \frac{550\,H}{v}$, where H is the maximum horse-power transmitted, and v the velocity of the pitch line of the wheel in feet per second, we may give these formulæ in a more convenient form:

$$t = x\sqrt{\frac{H}{v}}.$$

Where $x = 0{\cdot}587$ for cast iron,
„ $= 0{\cdot}821$ for brass,
„ $= 0{\cdot}891$ for wood.

Conversely, if a wheel having teeth t inches thick be given,

the horse-power it is capable of transmitting is given by the formula:

$$H = \frac{t^2 v}{x^2}.$$

Where $x^2 = 0{\cdot}344$ for cast iron,
„ $= 0{\cdot}674$ for brass,
„ $= 0{\cdot}795$ for wood.

From the following table the pressure at other velocities, and with another amount of horse-power, may be obtained by interpolation, remembering that the pressure varies inversely as the former, and directly as the latter. To this we have appended another table, giving the horses' power, which can be safely transmitted by wheels of different pitches when proportioned according to the table at page 34. The last of these tables has been calculated on the assumption that 400 lbs. per inch is the greatest working stress which is consistent with durability in ordinary cases. (See Appendices.)

RELATION OF HORSES' POWER TRANSMITTED AND VELOCITY AT THE PITCH CIRCLE TO PRESSURE ON TEETH.

Number of horses' power transmitted	Velocity in feet per second									
	1 ft.	3 ft.	5 ft.	7 ft.	9 ft.	11 ft.	13 ft.	15 ft.	20 ft.	25 ft.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1	550	183	110	79	61	50	42	37	28	22
2	1,100	367	220	157	122	100	85	73	55	44
3	1,650	550	330	236	183	150	127	110	83	66
4	2,200	733	440	314	244	200	169	146	110	88
5	2,750	917	550	393	306	250	212	183	138	110
10	5,500	1,833	1,100	786	611	500	423	367	275	220
15	8,250	2,750	1,650	1,179	917	750	635	550	413	330
20	11,000	3,667	2,200	1,571	1,222	1,000	846	733	550	440
25	13,750	4,583	2,750	1,964	1,527	1,250	1,058	917	688	550
30	16,500	5,500	3,300	2,357	1,833	1,500	1,269	1,100	825	660
40	22,000	7,333	4,400	3,143	2,444	2,000	1,692	1,467	1,100	880
50	27,500	9,167	5,500	3,928	3,055	2,500	2,115	1,833	1,375	1,100
60	33,000	11,000	6,600	4,714	3,667	3,000	2,538	2,200	1,650	1,320
70	38,500	12,833	7,700	5,500	4,278	3,500	2,962	2,567	1,925	1,540
80	44,000	14,667	8,800	6,285	4,889	4,000	3,385	2,933	2,200	1,760
90	49,500	16,500	9,900	7,071	5,500	4,500	3,808	3,308	2,475	1,980
100	55,000	18,333	11,000	7,857	6,111	5,000	4,231	3,667	2,750	2,200
110	60,500	20,167	12,100	8,643	6,722	5,500	4,654	4,033	3,025	2,420
120	66,000	22,000	13,200	9,423	7,333	6,000	5,077	4,400	3,300	2,640
130	71,500	23,833	14,300	10,214	7,944	6,500	5,500	4,767	3,575	2,860
140	—	25,667	15,400	11,000	8,556	7,000	5,923	5,133	3,850	3,080
150	—	27,500	16,500	11,786	9,167	7,500	6,346	5,500	4,125	3,300
160	—	29,333	17,600	12,571	9,778	8,000	6,769	5,867	4,400	3,520
170	—	31,167	18,700	13,357	10,389	8,500	7,192	6,233	4,675	3,740
180	—	—	19,800	14,143	11,000	9,000	7,615	6,600	4,950	3,960
190	—	—	20,900	14,929	11,611	9,500	8,038	6,967	5,225	4,180
200	—	—	22,000	15,714	12,222	10,000	8,462	7,333	5,500	4,400
300	—	—	33,000	23,571	18,333	15,000	12,692	7,700	8,250	6,600
400	—	—	44,000	31,428	24,444	20,000	16,923	8,067	11,000	8,800
500	—	—	55,000	39,285	30,555	25,000	21,154	8,433	13,750	11,000

TABLE SHOWING THE PITCH AND THICKNESS OF TEETH TO TRANSMIT A GIVEN NUMBER OF HORSES' POWER AT DIFFERENT VELOCITIES.

Pitch in inches	Thickness of teeth in inches	Velocity at Pitch line in feet per second												
		1	3	5	7	9	11	13	15	20	25	30	40	50
		H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.	H. P.
½	·22	·14	·42	·71	·99	1·26	1·5	1·8	2·1	2·8	3·5	4·2	5·6	7·1
¾	·33	·32	·95	1·59	2·22	2·75	3·5	4·1	4·7	6·3	7·9	9·5	12·7	15·9
1	·45	·59	1·77	2·95	4·12	5·31	6·5	7·7	8·8	11·8	14·7	17·7	23·6	29·5
1¼	·56	·91	2·74	4·56	6·38	8·22	10·0	11·9	13·7	18·2	22·8	27·4	36·5	45·6
1½	·68	1·34	4·03	6·72	9·41	12·09	14·8	17·5	20·2	26·9	33·6	40·3	53·7	67·2
1¾	·80	1·86	5·58	9·31	13·03	16·74	20·5	24·2	27·9	37·2	46·5	55·8	74·4	93·1
2	·92	2·46	7·38	12·31	17·23	22·14	27·1	32·0	36·9	49·2	61·5	73·8	98·4	123·1
2¼	1·04	3·14	9·43	15·72	22·01	27·29	34·6	40·9	47·2	62·9	78·6	94·3	125·7	157·2
2½	1·15	3·85	11·54	19·23	26·92	34·62	42·3	50·0	57·7	76·9	96·1	115·4	153·8	192·3
2¾	1·27	4·69	14·07	23·45	32·82	42·21	51·6	61·0	70·3	93·8	117·2	140·6	187·5	234·5
3	1·39	5·62	16·84	28·08	39·31	50·42	61·8	73·0	84·2	112·3	140·4	168·5	224·6	280·8
3¼	1·51	6·63	19·88	33·14	46·40	59·64	72·9	86·2	99·4	132·6	165·7	198·8	265·1	331·4
3½	1·62	7·63	22·89	38·15	53·40	68·67	83·9	99·2	114·4	152·6	190·7	228·9	305·1	381·5
3¾	1·74	8·80	26·40	44·00	61·61	79·20	96·8	114·4	132·0	176·0	220·0	264·0	352·0	440·0
4	1·86	10·06	30·17	50·29	70·40	90·50	110·6	130·7	150·8	201·1	251·4	301·7	402·3	502·9
4½	2·09	12·70	38·09	63·49	88·89	114·27	139·7	165·1	190·5	254·0	317·5	380·9	507·9	634·9
5	2·33	15·78	47·35	78·91	110·47	142·05	173·6	205·2	236·7	315·6	394·5	473·5	631·3	789·1
5½	2·56	19·05	57·15	95·26	133·36	171·45	209·6	267·7	285·8	381·0	476·3	571·5	762·0	952·6
6	2·80	22·79	68·37	113·96	159·54	205·11	250·7	316·3	341·9	455·8	569·7	683·7	911·6	1,139·6

TABLE SHOWING THE BREADTH OF TEETH REQUIRED TO TRANSMIT DIFFERENT AMOUNTS OF FORCE AT A UNIFORM PRESSURE OF 400 LBS. PER INCH.

Number of horses' power transmitted	Velocity of pitch line in Feet per second										
	1	3	5	7	9	11	13	15	20	25	30
	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.
1	1·4	0·5	0·3	0·2	0·15	0·12	0·11	0 09	0·07	0·05	0·05
2	2·7	0·9	0·6	0·4	0·3	0·25	0·21	0·18	0·14	0·11	0·09
3	4·1	1·4	0·8	0·6	0·5	0·38	0·32	0·27	0·21	0·17	0·14
4	5·5	1·8	1·1	0·8	0·6	0·50	0·42	0·37	0·28	0·22	0·18
5	6·9	2·3	1·4	1·0	0·8	0·62	0·53	0·46	0·35	0·28	0·23
10	13·7	4·6	2·7	2·0	1·5	1·3	1·06	0·92	0·69	0·55	0·46
15	20·6	6·9	4·1	2·9	2·3	1·9	1·6	1·37	1·03	0·83	0·69
20	34·2	9·2	5·5	3·9	3·1	2·5	2·1	1·83	1·38	1·10	0·92
25	41·2	11·4	6·9	4·9	3·8	3·1	2·6	2·3	1·72	1·38	1·14
30	55·0	13·8	8 2	5·9	4·6	3·8	3·2	2·8	2·06	1·65	1·38
40	68·8	18·3	11·0	7·9	6·1	5·0	4·2	3·7	2·75	2·20	1·83
50	82·5	22·9	13·7	9·8	7·6	6·3	5·3	4·6	3·44	2·75	2·29
60	96·2	27·5	16·5	11·8	9·1	7·5	6·4	5·5	4·1	3·30	2·75
70	110·0	32·1	19·2	13·8	10·7	8·8	7·4	6·4	4·8	3·85	3·21
80	123·8	36·7	22·0	15·7	12·2	10·0	8·5	7·3	5·5	4·40	3·67
90	137·5	41·2	24·8	17·7	13·8	11·2	9·5	8·2	6·2	4·95	4·12
100	151·2	45·8	27·5	19·6	15·3	12·5	10·6	9·1	6·9	5·50	4·58
110	165·0	50·4	30·3	21·6	16·8	13·7	11·6	10·1	7·5	6·05	5·04
120	178·8	55·0	33·0	23·5	18·3	15·0	12·7	11·0	8·3	6·6	5·50
130	—	59·8	35·7	25·5	19·8	16·3	13·8	11·9	8·9	7·2	5·98
140	—	64·2	38·5	27·5	21·4	17·5	14·8	12·8	9·6	7·7	6·42
150	—	68·7	41·3	29·4	22·9	18·7	15·8	13·7	10·3	8·2	6·87
160	—	73·3	44·0	31·4	24·5	20·0	16·9	14·6	11·0	8·8	7·33

CHAPTER II.

ON THE STRENGTH AND PROPORTIONS OF SHAFTS.

THE system of transmitting power from a common centre to a large number of machines, at some distance, is comparatively modern. In the operations of spinning and weaving by a consecutive series of machines, placed in rows, shafting became essential for distributing the power of the common prime mover. At first, the machines were brought as close to the prime mover as possible; and the early construction of mills—when the water-power was divided into separate falls—must be fresh in the recollection of many persons now living. In some cases, before the introduction of the steam engine, it was the custom to have a separate water-wheel to every machine, thus splitting up the power into as many parts as there were machines, or pairs of machines, to drive. In process of time, it was found more convenient, on the score of economy, to husband the water and concentrate the prime movers; hence one large water-wheel was constructed, around which the machinery was arranged, either in rows or otherwise, as best suited the work to be performed.

This principle, of the concentration of the motive power, destroyed the old system of separate buildings, and led to the employment of a large number of machines for the various processes of manufacture in one building. From this we derive the Factory system, in which any number of processes are carried on, the machinery being distributed over the different floors of a large building, and receiving motion from a single prime mover at a convenient distance. In this way, the power is conveyed by lines of shafting coupled together in lengths, adapted to the bays or divisions of the building. At first, the buildings were short, and shafting of great length was not required; gradually, more and more machines were concentrated in the same building, and shafting of 200 or 300 feet in length became necessary. To show to what an extent this system has

been carried, it may be mentioned, that in the large mills at Saltaire, the shafting, if placed in a single line, would extend for a distance of more than two miles. This progress has been chiefly due to the introduction of the steam engine, in place of water-wheels, because the available power is no longer limited by the circumstances of the locality in which the mill is placed.

This concentration of a great number of machines in one building is peculiar to the Factory system; and in the present highly-improved state of mechanical science and its application to the production of textile fabrics, it has become essential to economy in the manufacturing processes, that they should be carried on in the same building. Spinners and manufacturers are fully aware of the advantages peculiar to this system of concentration, so much so, that out of what would formerly have been considered a mere fractional saving, large profits and large fortunes are now made. In fact, the amalgamation of the different processes under one management and under one roof, gave rise to the Shed system, where the operations of the manufacture of cotton are carried on under what is called the "*saw-tooth*" roof, in order to bring the whole on the ground-floor under one inspection.

1. *The Material of which Shafting is constructed.*

The selection of the material for shafting is of great importance, and the uses to which it is to be applied require careful consideration. Formerly wood, with iron hoops and gudgeons, was universally employed; then cast iron was introduced; and subsequently wrought iron has in most cases superseded both. Wood, indeed, has become obsolete; but cast iron is as good as, if not superior to, wrought iron, in certain cases. The main and vertical shafts of a mill are generally of cast iron, both on account of its cheapness, and its high resistance to torsion. The vertical shafts, which convey the power from the first motion wheels to the different rooms of the mill, are more rigid and less subject to vibration when of cast iron; even the main horizontal shafting, when of large dimensions, is, if substantially fixed, quite as good, when of the same material, and much cheaper than wrought iron. Where the shaft is exposed to impact, or any irregularity of force, wrought iron has the

superiority; but in other cases, when the castings are sound and good, cast iron may be employed with perfect safety.

The dimensions required for a shaft, transmitting any given force, will depend on the resistance of the material of which it is composed. Consequently, the selection of material must be determined by the necessity for strength. Shafts may be considered as subject to two forces: a force producing simple flexure, arising from their own weight, the weight of the wheels and pulleys, and the strain of the belts; and a twisting force or torsion, arising from the power transmitted. If the flexure be great, the brasses will be much worn, vibration becomes considerable, and the disintegration of the machinery goes on in an accelerating ratio; it is therefore necessary to proportion shafting to the simple weight and direct transverse strain it has to sustain, so as to reduce the flexure within exceedingly narrow limits. In addition to this, the shafting, having to transmit a torsive force, must at least be capable of transmitting it without danger of rupture. In long and light shafting the tendency to flexure is usually greater than that to rupture by torsion; the former consideration will therefore determine the size of the shaft. In short axles, the danger from flexure almost disappears, and the strength of the shaft is determined by its resistance to torsion only. In all cases both conditions must be complied with, if security and permanence are to be obtained.

2. *Transverse Strain.*

Resistance to Rupture. The general formula for resistance to rupture, in the case of a bar or beam supported at each end and loaded in the centre, is

$$w = \frac{a\,d\,c}{l} \quad . \quad . \quad . \quad . \quad (1)$$

where w is the load in the centre, a the area of a section of the bar, perpendicular to the length; d the depth of the bar, and l its length. In this case c is derived from experiment, and is constant for similar bars or beams.

For rectangular bars this formula becomes,

$$w = \frac{c\,b\,d^2}{l} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where b is the breadth and d the depth.

The value of c, for rectangular bars found by Mr. Barlow, for various materials, is given in the following table. In applying these numbers to calculations, it must be remembered that a and d are to be taken in inches, and l in feet; then c, the centre breaking-weight, is found in lbs.

When the beam is supported at one end and loaded at the other, the formula is

$$w = \frac{c\,b\,d^2}{4l} \quad \ldots\ldots\ldots \quad (3).$$

Value of c for different Materials.

	lbs.		lbs.
English Malleable Iron	2050	Pitch Pine	544
Cast Iron	2548	Beech	518
Teak	820	Red Pine	447
Oak	400	Riga Fir	376
Canadian Oak . . .	588	Mar Forest Fir . . .	415
Ash	675	Larch	280

In my own experiments* I found the value of c for cast iron to range from 1606 to 2615, the mean value being about 2050, as given above for malleable iron. Wrought iron ranges from the value given above to 3000 lbs.

For cylindrical shafts supported horizontally the ultimate resistance to rupture is about

$$w = \frac{1500\,d^3}{l}\dagger \text{ for wrought iron,}$$

$$d = \sqrt[3]{\frac{w\,l}{1500}}$$

$$w = \frac{1200\,d^3}{l} \text{ for cast iron,}$$

$$d = \sqrt[3]{\frac{w\,l}{1200}}$$

where w is the centre breaking-weight in lbs., d the diameter in inches, and l the length between supports in feet, the shaft being supported at the ends and loaded in the middle.

* *On the Application of Cast and Wrought Iron to Building Purposes*, p. 70 et seq.

† The correct values of these fractions are $w = \frac{1472d^3}{l}$ and $w = \frac{1178d^3}{l}$, but whole numbers are more easily remembered.

If the cylindrical shaft be loaded at one end and supported at the other, these formulæ become

$$\text{W} = \frac{368\,d^3}{l} \text{ for wrought iron,}$$

$$d = \sqrt[3]{\frac{\text{W}\,l}{368}}$$

$$= \frac{295\,d^3}{l} \text{ for cast iron}$$

$$d = \sqrt[3]{\frac{\text{W}\,l}{295}}$$

If a beam be uniformly loaded over its entire length, it will sustain twice the load that would break it if placed at the centre.

If the load be placed at any point intermediate between the centre and the ends, the breaking-weight may be found by the following rule:—Divide four times the product of the distance in feet, of the weight from each bearing, by the whole distance in feet, and the quotient may be substituted for l in the formulæ above. That is, if x and y be its distances in feet from the two bearings respectively;

$$l = \frac{4xy}{(x+y)}$$

From these rules the strength of shafts may be calculated, in all the cases of ordinary practice, where the tendency to transverse fracture has to be guarded against, making the actual strength at least eight to ten times the strain to be carried. In shafting, however, it is not usually the transverse rupture, but the flexure produced by lateral stress, which limits the size of the shaft;—stiffness in fact becomes, in these cases, a more important element than strength.

The following formula has been given for the deflection of bars or beams loaded at the centre and supported at the ends:—

Let, d be the depth in inches;
b the breadth in inches;
L the length between supports in feet;
W the load in lbs.;
δ the deflection at the centre in inches;
M the modulus of elasticity;

then:— $\text{W} = \frac{\text{M}\,b\,d^3\,\delta}{560\,\text{L}^3}$; and if $b = d$—

$$d^4 = \frac{560\ L^3\ W}{M\ \delta} \text{ or } d = \sqrt[4]{\frac{560\ L^3\ W}{M\ \delta}} \quad . \ . \quad (4).$$

Or, in words, multiply the product of the load in lbs., and the cube of the length in feet, by 560, and divide by the product of the modulus of elasticity and the deflection assumed in inches; the fourth root of the quotient will be the side of a shaft of square section which would deflect δ inches with a weight of W lbs. placed at its centre.*

The following table gives the values of the modulus of elasticity for various materials:—

	Modulus of elasticity in lbs.
Cast iron . . .	13,000,000 to 22,907,000
„ mean . . .	17,000,000
Malleable iron . .	24,000,000 to 29,000,000
Steel . . .	29,000,000 to 42,000,000
Brass	8,930,000
Tin	4,608,000
Ash	1,600,000
Beech	1,353,600
Red pine, mean	1,700,000
Spruce, mean	1,600,000
Larch	900,000 to 1,360,000
English oak . . .	1,200,000 to 1,750,000
American oak	2,150,000

For a cylindrical shaft, the same formula will apply with another constant. I am not aware that this has been experimentally ascertained, but it has been given approximately as 952. Hence, for cylindrical shafts,

$$d^4 = \frac{952\ L^3\ W}{M\ \delta} \text{ or } d = \sqrt[4]{\frac{952\ L^3\ W}{M\ \delta}} \ldots (5).$$

In the work just quoted, these formulæ have been simplified, by fixing a maximum value for δ, the deflection. The writer assumes that, with shafting, the deflection ought never to exceed $\frac{1}{100}$ of an inch for every foot length of the shaft.

* *Engineer and Machinist's Assistant*, p. 135, from which formulæ (4), (5), (6), to (11), and (23), in their present convenient form for practical use, have been quoted. The fundamental formula, however, is due to Young (*Nat. Philos.* vol. ii. art. 326), and to Tredgold (Strength of Cast Iron, p. 208).

Substituting this value, and also the numerical value of the modulus of elasticity, he obtains the following formulæ:—

1. *For wood,*—taking M generally = 1,500,000, and $\delta = \frac{L}{100}$ inches.

Then, for square shafts, d being the depth of the side of the square—

$$d^4 = \frac{L^2 W}{35} \quad \ldots (6).$$

And for round shafts, d being the diameter in inches—

$$d^4 = \frac{L^2 W}{20} \quad \ldots (7).$$

2. *For cast iron* — taking M = 18,000,000 lbs. and L as before—

For square section, $d^4 = \frac{L^2 W}{412}$ ... (8).

For round section, $d^4 = \frac{L^2 W}{240}$ ... (9).

3. *For wrought iron* — taking M = 24,500,000 lbs. and δ as before—

For square section, $d^4 = \frac{L^2 W}{567}$ ... (10).

For round section, $d^4 = \frac{L^2 W}{334}$ ... (11).

By transposition, the formulæ given above become—

For wood—

Square section, $L = \sqrt{\frac{35\, d^4}{W}}$ ... (12).

$$W = \frac{35\, d^4}{L^2}$$

Round section, $L = \sqrt{\frac{20\, d^4}{W}}$ ... (13).

$$W = \frac{20\, d^4}{L^2} \quad \ldots (14).$$

For cast iron—

Square section, $L = \sqrt{\frac{412\, d^4}{W}}$ ... (15).

$$W = \frac{412\, d^4}{L^2} \quad \ldots (16).$$

$$\text{Round section, } \mathrm{L} = \sqrt{\frac{240\, d^4}{\mathrm{W}}} \quad \ldots (17).$$

$$\mathrm{W} = \frac{240\, d^4}{\mathrm{L}^2} \quad \ldots (18).$$

For wrought iron—

$$\text{Square section, } = \sqrt{\frac{567\, d^4}{\mathrm{W}}} \quad \ldots (19).$$

$$\mathrm{W} = \frac{567\, d^4}{\mathrm{L}^2} \quad \ldots (20).$$

$$\text{Round section, } \mathrm{L} = \sqrt{\frac{334\, d^4}{\mathrm{W}}} \quad \ldots (21).$$

$$\mathrm{W} = \sqrt{\frac{334\, d^4}{\mathrm{L}^2}} \quad \ldots (22).$$

When the weight is uniformly distributed over the length of the shaft, the general formula is

$$d^4 = \frac{270\, \mathrm{L}^3\, \mathrm{W}}{\mathrm{M}\, \delta} \text{ or } d = \sqrt[4]{\frac{270\, \mathrm{L}^3\, \mathrm{W}}{\mathrm{M}\, \delta}} \quad \ldots (23).$$

Substituting in this equation the same values of M and δ as before, we obtain the following formulæ:—

For wood—

$$d^4 = \frac{\mathrm{L}^2\, \mathrm{W}}{56} \text{ for square shafts.}$$

$$d^4 = \frac{\mathrm{L}^2\, \mathrm{W}}{32} \text{ for round shafts.}$$

For cast iron—

$$d^4 = \frac{\mathrm{L}^2\, \mathrm{W}}{666} \text{ for square shafts.}$$

$$d^4 = \frac{\mathrm{L}^2\, \mathrm{W}}{383} \text{ for round shafts.}$$

For wrought iron—

$$d^4 = \frac{\mathrm{L}^2\, \mathrm{W}}{907} \text{ for square shafts.}$$

$$d^4 = \frac{\mathrm{L}^2\, \mathrm{W}}{521} \text{ for round shafts.}$$

The following tables for cast and wrought iron round shafting, are calculated from the formulæ (9) and (11) for weights placed at the centre of a shaft supported at each end. In using them for cases in which the weight is distributed along its length, as in the case of the weight of the shaft itself, it must be remembered that a distributed weight produces $\frac{5}{8}$ths of the deflection of the same weight placed at the centre.

TABLE 1.—RESISTANCE TO FLEXURE. WEIGHTS PRODUCING A DEFLECTION OF $\frac{1}{1200}$TH OF THE LENGTH IN CAST IRON CYLINDRICAL SHAFTS.

Length between supports in feet	Diameter of Shaft in Inches																			
	1	1½	2	2½	3	3½	4	4½	5	5½	6	7	8	9	10	12	14	16	18	20
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	tons	tons	tons	tons	tons
5	9·6	49	154	375	778	1,441	2,458	3,937	6,000	8,785	12,442	23,050	39,322	62,986	96,000	88·9	164·6	280·9	449·9	685·7
6	6·7	34	107	261	540	1,000	1,707	2,734	4,166	6,100	8,640	16,007	27,307	43,741	66,660	61·7	114·3	195·1	312·4	476·2
7	4·9	25	78	191	397	735	1,254	2,008	3,061	4,482	6,348	11,760	20,062	31,673	48,980	45·3	84·0	143·3	229·5	349·8
8	3·7	19	60	146	304	563	960	1,538	2,344	3,431	4,860	9,004	15,360	24,604	37,500	34·7	64·3	109·7	175·7	267·9
9	—	15	47	116	240	445	758	1,215	1,852	2,711	3,840	7,115	12,136	19,440	29,630	27·5	50·8	86·7	138·9	211·6
10	—	12	38	94	194	360	615	984	1,500	2,196	3,110	5,763	9,830	15,747	24,000	22·2	41·2	70·2	112·5	171·4
11	—	10	32	77	160	298	508	814	1,240	1,815	2,571	4,763	8,124	13,014	19,834	18·4	34·0	58·0	93·0	141·7
12	—	8	27	65	135	251	427	683	1,042	1,525	2,160	4,002	6,827	10,935	16,667	15·4	28·6	48·8	78·1	119·1
13	—	—	23	56	115	213	364	583	888	1,299	1,840	3,410	5,817	9,317	14,201	13·1	24·4	41·5	66·6	101·4
14	—	—	19	48	99	184	314	502	765	1,121	1,587	2,940	5,016	8,034	12,245	11·3	21·0	35·8	57·4	87·4
15	—	—	17	42	86	160	273	437	666	976	1,383	2,561	4,369	7,000	10,667	9·9	18·3	31·2	50·0	76·2
16	—	—	15	37	76	141	240	384	586	858	1,215	2,251	3,840	6,151	9,374	8·7	16·1	27·4	43·9	66·9
17	—	—	13	33	67	125	213	341	519	760	1,076	1,994	3,401	5,448	8,305	7·7	14·2	24·3	39·0	59·3
18	—	—	12	29	63	112	192	309	471	686	960	1,779	3,034	4,860	7,407	6·9	12·7	21·7	34·7	52·9
19	—	—	11	26	54	100	173	277	423	615	868	1,606	2,738	4,397	6,700	6·2	11·4	19·6	31·3	47·9
20	—	—	10	23	48	90	154	246	375	550	778	1,441	2,458	3,937	6,000	5·5	10·3	17·5	28·1	42·9

TABLE 2.—RESISTANCE TO FLEXURE. WEIGHTS PRODUCING A DEFLECTION OF $\frac{1}{1200}$TH OF THE LENGTH IN WROUGHT IRON CYLINDRICAL SHAFTS.

Length between bearings in feet	Diameter of Shaft in Inches																		
	1	1½	2	2½	3	3½	4	4½	5	6	7	8	9	10	12	14	16	18	20
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	tons	tons	tons	tons	tons
5	13·4	68	214	522	1,082	2,005	3,420	5,478	8,350	17,314	32,078	54,724	87,654	133,600	123·6	229·1	391·0	626·0	954
6	9·3	47	148	363	751	1,392	2,375	3,804	5,799	12,024	22,277	38,003	60,871	92,780	85·9	159·1	272·0	435·0	663
7	6·8	35	109	267	552	1,023	1,745	2,795	4,260	8,834	16,367	27,920	44,721	68,163	63·1	116·9	200·0	319·4	487
8	5·2	26	84	204	423	783	1,336	2,140	3,262	6,764	12,531	21,376	34,240	52,188	48·3	89·5	153·0	244·6	373
9	—	21	66	161	334	619	1,055	1,691	2,577	5,344	9,900	16,890	27,053	41,235	38·1	70·7	121·0	193·2	295
10	—	17	53	130	223	501	855	1,370	2,087	4,329	8,020	13,681	21,913	33,400	30·9	57·3	97·7	156·5	231
11	—	14	44	108	188	414	707	1,132	1,725	3,577	6,628	11,306	18,110	27,603	25·5	47·3	80·7	129·4	197
12	—	12	37	91	160	348	594	952	1,450	3,006	5,569	9,500	15,218	23,195	21·5	39·8	67·9	108·7	166
13	—	10	31	77	149	297	507	810	1,235	2,561	4,745	8,095	12,966	19,763	18·3	33·9	57·8	92·6	141
14	—	—	27	68	138	256	436	699	1,065	2,208	4,091	6,980	11,180	17,041	15·8	29·2	49·9	79·9	122
15	—	—	24	60	122	223	380	609	928	1,924	3,564	6,080	9,740	14,844	13·7	25·5	43·4	69·6	106
16	—	—	21	51	106	196	334	535	816	1,691	3,133	5,344	8,560	13,047	12·0	22·4	38·1	61·1	93·2
17	—	—	19	46	95	173	296	474	722	1,498	2,775	4,734	7,582	11,557	10·7	19·8	33·8	54·2	82·5
18	—	—	17	42	84	157	268	430	655	1,359	2,518	4,296	6,880	10,488	9·7	18·0	30·6	48·3	74·8
19	—	—	15	37	76	141	240	386	589	1,221	2,261	3,858	6,179	9,419	8·7	16·1	27·5	43·5	67·2
20	—	—	13	33	68	125	213	342	522	1,082	2,005	3,420	5,478	8,350	7·7	14·3	24·4	39·1	59·6

From the foregoing it will be seen, that the weights given in the tables are correct indications of the load required in the centre to produce a deflection of the $\frac{1}{1200}$th of the length of the shaft.* This fraction is not however the universal standard among millwrights; on the contrary, there appears to be no recognised standard in practice, by which the deflection from a given weight can be ascertained, and although $\frac{1}{1200}$ may, in many cases, give a larger area with increased weight, in shafts that are not heavily loaded in the middle, nevertheless it is important that the shafts, when loaded as above, should not bend more than $\frac{1}{1200}$th of their length. In cases where the load is light and equally distributed, lighter and smaller shafts would suffice.

The following tables give the deflection of cylindrical shafts with their own weight:—

TABLE 3.—DEFLECTION ARISING FROM THE WEIGHT OF THE SHAFT. CAST IRON CYLINDRICAL SHAFTS.

Length between bearings in feet	Diameter of Shaft in Inches								
	1	2	4	6	8	10	12	14	16
	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.
5	·004	·001	·000	·000	·000	·000	·000	·000	·000
10	·067	·017	·004	·002	·001	·001	·001	·000	·000
15	·338	·085	·021	·009	·005	·003	·002	·002	·001
20	1·067	·267	·067	·029	·017	·011	·007	·005	·004
25	2·603	·651	·163	·073	·041	·026	·018	·013	·010

TABLE 4.—DEFLECTION ARISING FROM THE WEIGHT OF THE SHAFT. WROUGHT IRON CYLINDRICAL SHAFTS.

Length between bearings in feet	Diameter of Shaft in Inches								
	1	2	4	6	8	10	12	14	16
	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.	ins.
5	·003	·001	·000	·000	·000	·000	·000	·000	·000
10	·050	·013	·003	·001	·001	·001	·000	·000	·000
15	·256	·064	·016	·007	·004	·003	·002	·001	·001
20	·808	·202	·051	·022	·013	·008	·005	·004	·003
25	1·972	·493	·123	·055	·031	·020	·013	·010	·008

The above tables clearly indicate the deflection of shafts of different lengths by their own weight, and will be a guide to the

* This standard is the one assumed by Tredgold (Strength of Cast Iron, p. 210).

millwright in calculating the distance of the bearings between which they revolve. It is important in shafting, when extended in long ranges, that there should not be any serious deflection, either from the weight of the shaft, or lateral stress; I have always found that a stiff shaft, although heavier in itself, is lighter to retain in motion than a smaller one which bends to the strain.

3. *Torsion.*

In addition to the lateral flexure from transverse forces, shafting is subjected to a wrenching or twisting, from the power transmitted acting tangentially to its circumference. This causes one end of the shaft to revolve in relation to the other end, through a smaller or greater angle, known as the angle of torsion, and, if sufficient force be applied, this angle increases till the resistance of the material is overcome, and the shaft gives way.

Coulomb laid the basis of our knowledge of the resistance to torsion of cylindrical bodies, and he verified his theoretical deductions by admirably-contrived experiments, on a small scale. He showed that in wires where the diameter is small in relation to the length, the angles of torsion are in proportion to the length, and reciprocally proportional to the moment of inertia of the base of the cylinder in relation to its centre. He also discovered that each wire acquired a permanently acceleration-varying torsion, according to the degree in which it departed from its primitive position, and that these permanent torsions have no fixed relation to the temporary torsions, coexisting with the application of the moving force. With the same wire he found the torsion to be in proportion to the force applied; with the same length and force inversely as the fourth power of the diameter.

These deductions are expressed by the following formula:—

$$\theta = \frac{2\,\mathrm{R}}{\pi\,\mathrm{G}} \times \frac{\mathrm{W}\,l}{r^4}$$

where θ is the angle of torsion, r the radius, and l the length of the wire, R the leverage at which the weight W acts, and G the modulus of torsion for the material: being about $\frac{2}{5}$ths of the modulus of elasticity.

In 1829 a paper was communicated to the Royal Society by Mr. Bevan, containing experimental determinations of the modulus of torsion for a large number of substances, of which the most important are given below.

Let δ be the deflection of a prismatic shaft of a given length l when strained by a given force w in lbs., acting at right angles to the axes of the prism and at a leverage r; let d be the side of the square section of the shaft, l, r, δ, d, being in inches;

$$\delta = \frac{r^2 lw}{d^4 \mathrm{T}}$$

where T is the modulus of elasticity in the following table.

If the transverse section of the prism be a parallelogram, let b be the breadth and d the depth; then Mr. Bevan gives the formula—

$$\delta = \frac{(d+b)\, lr^2 w}{2\, b\, d^3 \mathrm{T}}$$

If the torsion be required in degrees (Δ), then let $\rho = 57{\cdot}29578$,

$$\Delta = \frac{r\rho\, lw}{d^4 \mathrm{T}}, \text{ for square shafts.}$$

For example,

$$\Delta = \frac{r\, l\, w}{31000\, d^4} \text{ for wrought iron and steel,}$$

$$= \frac{r\, l\, w}{16600\, d^4} \text{ for cast iron.}$$

A very careful experimental study of the effect of torsion on various materials has been made by Mr. M. G. Wertheim, and was presented to the Académie des Sciences in 1855. The general results at which he has arrived may be stated as follows:—

1. The total angle of torsion consists of two parts, of which one is purely temporary, whilst the other persists after the force has ceased to act. It is not possible to assign the limit at which the permanent torsion begins to be sensible, nor has it any fixed relation to the temporary torsion; it augments at first very slowly, afterwards more rapidly, till the bar breaks.*

* We have many practical instances of this tendency to rupture which at first appear only temporary, but a continuation of the same action, particularly in long

TABLE 5.—VALUES OF MODULUS OF TORSION ACCORDING TO MR. BEVAN.

Material	Specific gravity	Modulus of torsion (T)	
		lbs.	
Ash	—	20,300	
Beech	—	21,243	
Elm	—	13,500	
Scotch fir	—	13,700	
Hornbeam	·86	26,400	
Larch	·58	18,967	
English oak	—	20,000	
Memel pine	—	15,000	
American pine	—	14,750	
Teak	—	16,800	Old and partially decayed
Teak, African	—	27,300	
Iron, English wrought	—	1,775,000	(Mean)
Steel	—	1,753,000	(Mean)
Iron (cylindrical)	—	1,910,000	
„ „	—	1,700,000	
„ (square)	—	1,617,000	
„ „	—	1,667,000	
„ „	—	1,951,000	
Cast iron	—	940,000	
„ „	—	963,000	
„ „	—	952,000	
„ „	—	951,600	(Mean)
Bell-metal	—	818,000	

2. The temporary angles are not rigorously proportional to the moments of the forces applied.

3. The mean angles of torsion are not rigorously proportional to the length of the bar, increasing, although very slightly, in proportion to the length, as the bars are made shorter.

4. The interior cavity of all hollow homogeneous bodies diminish by torsion, and this diminution is proportional to the

ranges of shafts, in process of time, developes itself in the form of a permanent deterioration which ultimately leads to fracture. This was strikingly exemplified in a range of shafts, 220 feet long, tapering from three inches diameter at the driving end, to two inches diameter at the other.

The work done by these shafts was uniform throughout, but it was soon found that the shaft had made nearly 1·16 revolutions at the driven end of the room, before it began to move at the other. The result was a continued series of jerks or accelerated and retarded motion, injurious to the machinery, and destructive to the work it had to perform. It was, moreover, injurious to the shafts, particularly in the middle, where the twist was severely felt, and would have led to rupture, but from the circumstance that they had to be renewed with a stiffer and stronger range.

length and to the square of the angle of torsion for unity of length.

5. For cylindrical bodies Mr. Wertheim gives the following formulæ:—

Let ψ be the mean temporary angle of torsion, for
$p = 1$ kilogramme, and
$l = 1$ mètre;
p = the sum* of the two weights producing torsion and constituting a couple in kilogrammes;
R = the leverage at which the weight p acts;
l = length of the bar subject to torsion, in millimètres;
r = the exterior radius of the section of the bar, in millimètres;
r_1 = the interior radius of hollow bars, in millimètres;
E = the modulus of elasticity of the material obtained from experiments on tension.

Then, for solid bars:†—

$$\psi = \frac{16}{3} \cdot \frac{180}{\pi^2} \cdot \frac{pR}{E} \cdot \frac{l}{r^4}$$

and for hollow cylinders

$$\psi = \frac{16}{3} \cdot \frac{180}{\pi^2} \cdot \frac{pR}{E} \cdot \frac{l}{r^4 - r_1^4}$$

In the following experiments, $p = 1$ kilogramme, E = 247·5 millimètres, $l = 1000$ millimètres.

Résumé of Experiments on Cylinders of Circular Section.

—	Material	Radius r	Coefficient of elasticity, E	Mean angle of torsion	
				By formula	By experiment
		mm.		° ′ ″	° ′ ″
1	Iron	8·220	17,805	0 17 46·1	0 17 52·1
2	Iron	5·501	„	1 28 0·8	1 26 31·3
3	Cast steel . . .	5·055	19,542	1 53 12·0	1 51 13·4
4	Copper . . .	5·031	9,395	3 59 59·1	3 54 6·0
5	Glass . . .	3·535	6,200	24 51 56·0	24 15 34·7
6	Glass . . .	3·4225	„	28 18 2·0	28 30 14·0

* In Mr. Wertheim's experiments equal weights, acting in opposite directions at the same leverage, were hung one on each side of the bar, subjected to torsion.

† The above formulæ may be used with English measures, E being taken from English tables, if p be given in lbs. and r, l, and R in inches.

RÉSUMÉ OF EXPERIMENTS ON THE TORSION OF HOLLOW CYLINDERS OF COPPER.

	External radius (r)	Internal radius (r)	Coefficient of elasticity from tension (E)	Angle of torsion (ψ)	
				By formula	By experiment
				° ′ ″	° ′ ″
53	11,525	10,021	10,917	0 17 30·2	0 20 0·6
54	7,082	4,955	10,444	1 12 18·3	1 16 52·9
55	5,047	30,315	10,276	4 9 4·0	4 6 54·7
7	5,602	24,665	9,665	2 37 40·4	2 33 38·2
8	45,605	2,478	9,855	6 11 10·3	6 0 53·8
9	36,955	2,471	10,645	15 9 14·4	15 42 37·3

The accordance, in these tables, between the formulæ and the experiments is very satisfactory, especially considering that the value of E cannot be determined with perfect accuracy. The errors do not generally exceed $\frac{1}{80}$th, and the observed angles are smaller than those found by calculation, except in the case of the cylinders 9, 53, and 54.

For bars of elliptical section M. Wertheim has deduced the formula

$$\psi = \frac{8}{3} \cdot \frac{180}{\pi^2} \cdot \frac{p\,\mathrm{R}}{\mathrm{E}} \cdot \frac{l(c_1^2 + c_2^2)}{c_1^3\, c_2^3}$$

where c_1 and c_2 are the two semiaxes of the ellipse, the other letters remaining as before.

RÉSUMÉ OF EXPERIMENTS ON THE TORSION OF ELLIPTICAL BARS.

	Material	Semiaxes		Coefficient of elasticity by tension (E)	Mean angle of torsion (ψ)	
		c_1	c_2		By formula	By experiment
		mm.	mm.		° ′ ″	° ′ ″
11	Cast steel . .	7,105	3,697	19,085	2 13 56·7	2 10 55·4
12	,, . .	9,900	25,075	,,	4 18 0·1	4 13 18·2
13	Copper . .	7,062	3,669	9,634	4 32 56·7	4 30 41·2
14	,, . .	9,875	2,498	,,	8 38 11·2	8 54 33·9

For bars of rectangular section the formula becomes

$$\psi = \frac{180}{\pi^2} \cdot \frac{1}{2} \cdot \frac{p\,\mathrm{R}}{\mathrm{E}} \cdot \frac{l(a^2 + b^2)}{a^3\, b^3}$$

But it is necessary to apply a coefficient of correction c to the

calculated angle such that if ψ_1 be the calculated angle of torsion, and ψ_2 the angle found by experiment, then $c=\frac{\psi_1}{\psi_2}$. This coefficient varies with the ratio $\frac{a}{b}$ of the sides of the bar; thus, when $l=500$ millimètres, and the section was 36 millimètres square

$\frac{a}{b}$	1	2	4	8
Value of coefficient	0·8971	0·9617	0·9520	0·9878

It varies also with the ratio $\frac{l}{b}$ and with the moment of the couple p R.

For the ultimate resistance of cylindrical shafts to rupture by torsion, Professor W. J. M. Rankine gives the following formula:*

Let l denote the length in inches of the lever, such as a crank, at the end of which a wrenching or twisting force is applied to an axle. Let W be the working load in pounds, multiplied by a suitable factor of safety (usually six); then

$$W\,l=M$$

is the wrenching moment in inch pounds.

For a solid axle let h be its diameter; then

$$M=\frac{f h^3}{5{\cdot}1} \text{ and } h=\sqrt[3]{\frac{5{\cdot}1\,M}{f}}$$

For a hollow axle let h_1 be the external, and h_0 the internal diameter in inches; then

$$M=\frac{f(h_1^4-h_0^4)}{5{\cdot}1h_1}=\frac{f h_1^3}{5{\cdot}1}\cdot\left(1-\frac{h_0^4}{h_1^4}\right)$$

$$\text{and } h_1=\sqrt[3]{\left\{\frac{5{\cdot}1\,M}{f\left(1-\frac{h_0^4}{h_1^4}\right)}\right\}}$$

The values of the modulus of wrenching f are—

for cast iron about 30000,
for wrought iron „ 54000,

* Manual of Applied Mechanics, p. 355. Manual of Steam Engine, p. 78.

and taking six as the factor of safety, if we put the working moment of torsion in the formulæ instead of the wrenching moment, we may put instead of f

for cast iron 5000,
for wrought iron . . . . 9000.

Hence we get for w, the working stress, with solid shafts,

$$w_1 = \frac{5000\,h^3}{5{\cdot}1\,l} = \frac{980\,h^3}{l} \text{ for cast iron } \ldots \quad (2)$$

$$= \frac{9000\,h^3}{5{\cdot}1\,l} = \frac{1765\,h^3}{l} \text{ for wrought iron. } \ldots \quad (3.)$$

On this principle I have calculated the following tables (pages 68, 69), giving the safe moment of torsion for cylindrical cast and wrought iron shafts, and also the working stress to which they may be subjected at the circumference of pulleys or wheels of various diameters. In cases where the horses' power transmitted by a shaft is given instead of the stress, the latter may be found by the table on page 47.

The greatest angle of torsion, which it is safe to allow in a line of shafting, is determined by the extension of the material within the elastic limits. If $\frac{1}{1200}$th of the length be assumed as the maximum extension with the safe working load, then the shaft must be so proportioned that the angle of torsion is less than that given by the following formula

$$\psi = \frac{2284\,\text{L}}{1000\,d} \quad \ldots \quad (4)$$

where L is the length of the shaft in feet, d its diameter in inches, and ψ the angle of torsion in degrees.

It is convenient to estimate the ultimate resistance of shafts to torsion, not only as a statical pressure acting at a leverage, but also in horses' power. Now the stress resulting from the transmission of power must evidently increase in proportion to the power, and decrease in proportion to the velocity. A shaft will transmit 100 horses' power at 80 revolutions a minute with no more stress than it would transmit 50 horses' power at 40 revolutions, or 25 horses' power at 20 revolutions. Hence the

TABLE 6.—SAFE WORKING TORSION FOR CAST-IRON SHAFTS.

Diameter of Shaft in inches	($w_1 l$) Working moment of torsion in inch lbs.	Working Stress in lbs. at the following Radii, or W_1										
		6 ins.	9 ins.	12 ins.	15 ins.	18 ins.	21 ins.	24 ins.	27 ins.	30 ins.	42 ins.	60 ins.
1	980	163	109	81	64	54	46	41	36	32	23	16
1½	3,309	552	368	276	220	184	158	138	122	110	79	55
2	7,843	1,307	871	653	522	435	372	326	290	261	186	131
2½	15,320	2,553	1,702	1,276	1,020	851	730	638	567	510	365	255
3	26,470	4,411	2,941	2,206	1,764	1,470	1,260	1,103	980	882	630	441
3½	42,030	7,005	4,670	3,502	2,802	2,335	2,002	1,751	1,556	1,401	1,001	701
4	62,740	10,457	6,971	5,228	4,182	3,485	2,988	2,614	2,323	2,091	1,494	1,046
4½	89,350	14,891	9,928	7,445	5,956	4,964	4,254	3,722	3,309	2,978	2,127	1,489
5	122,550	20,425	13,617	10,212	8,170	6,809	5,834	5,106	4,539	4,085	2,917	2,043
5½	163,110	27,185	18,123	13,592	10,874	9,061	7,766	6,796	6,041	5,437	3,883	2,718
6	211,760	35,293	23,528	17,646	14,116	11,764	10,084	8,823	7,842	7,058	5,042	3,529
6½	269,240	44,873	29,916	22,436	17,950	14,958	12,820	11,218	9,972	8,975	6,410	4,487
7	336,280	56,047	37,364	28,023	22,418	18,682	16,012	14,012	12,454	11,209	8,006	5,605
7½	413,600	68,933	45,955	34,466	27,572	22,977	19,696	17,233	15,318	13,786	9,848	6,893
8	501,970	83,661	55,774	41,830	33,464	27,887	23,904	20,915	18,591	16,732	11,952	8,366
8½	602,100	100,350	66,900	50,175	40,140	33,450	28,672	25,088	22,300	20,070	14,336	10,035
9	714,720	119,120	79,413	59,560	47,648	39,706	34,034	29,780	26,471	23,824	17,017	11,912
9½	840,570	140,095	93,396	70,047	56,038	46,698	40,026	35,024	31,132	28,019	20,013	14,010
10	980,000	163,333	108,888	81,666	65,332	54,444	46,666	40,833	36,296	32,666	23,333	16,333
11	1,304,900	217,483	144,988	108,741	86,994	72,494	62,138	54,371	48,329	43,497	31,069	21,748
12	1,694,100	282,350	188,233	141,175	112,940	94,116	80,672	70,587	62,744	56,470	40,336	28,235
13	2,154,000	359,000	239,333	179,500	143,600	119,666	102,570	89,750	79,777	71,800	51,285	35,900
14	2,690,200	448,366	298,911	224,183	179,346	149,455	128,104	112,091	99,637	89,673	64,052	44,837
15	3,308,800	551,466	367,644	275,733	220,586	183,772	157,562	137,866	122,514	110,293	78,781	55,147
16	4,015,700	669,283	445,200	334,641	267,712	222,600	191,224	167,321	148,400	133,856	95,612	66,928
17	4,816,800	802,800	535,200	401,400	321,120	267,600	229,370	200,700	178,400	160,560	114,685	80,280
18	5,718,000	953,000	635,333	476,500	381,200	317,666	272,286	238,250	211,777	190,600	136,143	95,300
19	6,724,600	1,120,766	747,177	560,383	448,306	373,588	320,218	280,191	249,059	224,153	160,109	112,077
20	7,843,000	1,307,166	871,444	653,583	522,866	435,722	375,762	326,791	290,481	261,433	186,881	130,717

TABLE 7.—SAFE WORKING TORSION FOR WROUGHT-IRON SHAFTS.

Diameter of Shaft in inches	(w,l) Working moment of torsion in inch lbs.	Working Stress in lbs. at the following Radii										
		6 ins.	9 ins.	12 ins.	15 ins.	18 ins.	21 ins.	24 ins.	27 ins.	30 ins.	42 ins.	60 ins.
1	1,765	294	196	147	118	98	84	73	65	59	42	29
1½	5,956	923	662	496	396	331	284	248	221	198	142	99
2	14,120	2,353	1,569	1,176	942	784	672	588	523	471	336	235
2½	27,570	4,595	3,063	2,297	1,838	1,531	1,312	1,148	1,021	919	656	460
3	47,650	7,942	5,294	3,971	3,176	2,647	2,270	1,985	1,764	1,588	1,135	794
3½	75,660	12,610	8,406	6,305	5,044	4,203	3,602	3,152	2,802	2,522	1,801	1,261
4	112,940	18,823	12,549	9,411	7,530	6,274	5,378	4,705	4,183	3,765	2,689	1,882
4½	160,805	26,801	17,867	13,400	10,720	8,933	7,658	6,700	5,956	5,360	3,829	2,680
5	220,590	36,765	24,510	18,382	14,706	12,255	10,504	9,191	8,170	7,353	5,252	3,676
5½	293,600	48,933	32,622	24,466	19,572	16,311	13,980	12,233	10,874	9,786	6,990	4,893
6	381,180	63,530	42,353	31,765	25,412	21,176	18,152	15,882	14,117	12,706	9,076	6,353
6½	484,630	80,771	53,848	40,385	32,308	26,924	23,078	20,192	17,949	16,154	11,539	8,077
7	605,290	100,881	67,254	50,440	40,352	33,627	28,822	25,220	22,418	20,176	14,411	10,088
7½	744,480	124,080	82,720	62,040	49,632	41,360	35,452	31,020	27,573	24,816	17,726	12,408
8	903,530	150,588	100,392	75,294	60,234	50,196	43,024	37,647	33,464	30,117	21,512	15,059
8½	1,083,800	180,633	120,422	90,316	72,254	60,211	51,610	45,158	40,140	36,127	25,805	18,063
9	1,286,500	214,416	142,944	107,208	85,766	71,472	61,262	53,604	47,648	42,883	30,631	21,442
9½	1,513,000	252,166	168,111	126,083	100,866	84,055	72,048	63,041	56,037	50,433	36,024	25,217
10	1,765,000	294,166	196,111	147,083	117,666	98,055	84,048	73,541	65,370	58,833	42,024	29,417
11	2,348,800	391,466	260,966	195,733	156,586	130,483	111,848	97,866	86,988	78,293	55,924	39,147
12	3,049,400	508,233	338,822	254,116	203,292	169,411	139,496	127,058	112,941	101,646	69,748	50,823
13	3,877,100	646,123	430,788	323,091	258,474	215,394	184,624	161,545	143,596	129,237	92,312	64,618
14	4,842,300	807,050	538,033	403,525	322,820	269,016	230,586	201,762	179,344	161,410	115,293	80,705
15	5,955,800	992,633	661,755	496,316	397,054	330,877	283,610	248,158	220,585	198,527	141,805	99,263
16	7,228,200	1,204,700	803,133	602,350	481,880	401,566	344,200	301,175	267,711	240,940	172,100	120,470
17	8,670,100	1,445,016	963,366	722,508	578,006	481,683	412,862	361,254	321,122	289,003	206,431	144,501
18	10,292,000	1,715,333	1,143,555	857,666	686,132	571,777	490,096	428,833	381,185	343,066	245,048	171,533
19	12,104,000	2,017,333	1,344,888	1,008,666	806,932	672,444	576,380	504,333	448,296	403,466	288,190	201,733
20	14,120,000	2,353,333	1,568,888	1,176,666	941,332	784,444	672,380	588,333	522,962	470,666	336,190	235,333

torsion varies as $\frac{H}{R}$, where H is the number of horses' power per minute, and R the number of revolutions per minute.

Buchanan's rules for the power transmitted by shafts are:*—

For fly-wheel shafts

$$d = \sqrt[3]{\left\{\frac{H}{R} \times 400\right\}}$$

For shafts of water-wheel gearing and other heavy work,

$$d = \sqrt[3]{\left\{\frac{H}{R} \times 200\right\}}$$

For shafts of ordinary mill gearing

$$d = \sqrt[3]{\left\{\frac{H}{R} \times 100\right\}}$$

An ordinary allowance for wrought iron shafting in practice is

$$d = \sqrt[3]{\left\{\frac{H}{R} \times 250\right\}} \quad . \quad . \quad . \quad . \quad . \quad (5.)$$

From the foregoing observations in regard to torsion, and the power of transmission of shafts at different velocities, it is a desideratum of much importance to the engineer, so to proportion shafts in relation to their lengths as well as velocities, as to be within the limits of sensible permanent torsion and flexure,† and at the same time to increase the speeds in a given ratio to the velocities of the machine and the nature of the work it has to execute. In the above disquisition we have only given the law and the safe measure of torsion as regards length and area, but much must still depend on the calculation and judgment of the millwright and engineer; in its application to the character of the work they have to perform, and the resistances they have to overcome.

From formula (5.) the following table (page 71) has been calculated, giving the diameter necessary to transmit from 1 to 150 horses' power at from 10 to 1,000 revolutions per minute.

* These rules will be found in the second edition of Buchanan, at pages 328 *et seq.*

† Although we speak of the limits of permanent torsion, we are not prepared to fix these limits, as we find that what produces a permanent set in any material, however minute a fraction it may be, will in process of time, if continued, and often repeated, lead to fracture. This law applies to every description of strain or material, and we may therefore consider that there are limits to endurance, however distant that may be.

TABLE 8.—DIAMETER OF WROUGHT-IRON SHAFTING NECESSARY TO TRANSMIT WITH SAFETY VARIOUS AMOUNTS OF FORCE.

Horses' power safely transmitted	Diameter of Shaft in inches, with the following revolutions per minute											
	10	25	50	75	100	150	200	250	300	400	500	1000
1	2·92	2·15	1·71	1·50	1·36	1·20	1·09	1·00	·94	·85	·79	·63
2	3·68	2·71	2·15	1·91	1·71	1·49	1·36	1·26	1·20	1·09	1·00	·79
3	4·22	3·11	2·47	2·15	1·95	1·71	1·54	1·44	1·36	1·23	1·14	·91
4	4·64	3·42	2·71	2·35	2·15	1·91	1·71	1·36	1·49	1·36	1·26	1·00
5	5·00	3·68	2·92	2·57	2·32	2·00	1·84	1·71	1·61	1·45	1·36	1·09
10	6·30	4·64	3·68	3·21	2·92	2·57	2·11	2·15	2·03	1·84	1·71	1·36
15	7·21	5·31	4·22	3·68	3·35	2·92	2·66	2·46	2·32	2·21	1·95	1·55
20	7·94	5·85	4·64	4·06	3·68	3·21	2·92	2·71	2·56	2·32	2·15	1·71
30	9·09	6·69	5·31	4·64	4·22	3·68	3·34	3·11	2·92	2·66	2·46	1·95
40	10·00	7·37	5·85	5·10	4·64	4·06	3·68	3·42	3·21	2·92	2·71	2·15
50	—	7·94	6·30	5·51	5·00	4·36	3·96	3·68	3·46	3·14	2·92	2·32
60	—	8·43	6·69	5·85	5·31	4·64	4·22	3·91	3·68	3·35	3·11	2·46
70	—	8·88	7·05	6·15	5·59	4·89	4·44	4·12	3·88	3·52	3·27	2·60
80	—	9·28	7·37	6·44	5·84	5·10	4·64	4·31	4·05	3·68	3·42	2·71
90	—	9·65	7·66	6·69	6·08	5·31	4·83	4·48	4·22	3·83	3·56	2·82
100	—	10·00	7·94	6·93	6·30	5·51	5·00	4·64	4·36	3·96	3·68	2·92
110	—	—	8·19	7·16	6·50	5·67	5·16	4·79	4·51	4·10	3·80	3·01
120	—	—	8·43	7·37	6·69	5·85	5·31	4·93	4·64	4·22	3·91	3·11
130	—	—	8·66	7·57	6·88	6·01	5·46	5·06	4·76	4·33	4·02	3·19
150	—	—	9·09	7·94	7·21	6·30	5·72	5·31	5·00	4·55	4·22	3·35

4. *Velocity of Shafts.*

As the quality of the material employed for the construction of shafts enters largely into the calculation of their strength, so also the velocity at which they revolve becomes an important element in the calculation of the work transmitted by them. In all cases where machinery has to be driven at a high speed, it is advantageous and even essential to run the shafting at a proportionate velocity. If, for example, there are a series of machines running at 500 revolutions per minute, it will be advisable to run the shafts at half that speed, by which means the following very important advantages will be gained.

There will be a great saving in the weight of the shafts, for with a slow motion of 50 revolutions per minute, fully three times the weight would be necessary to transmit the same power. There would also be a saving in original cost in the power absorbed, and in maintenance.

Shafts running at low velocities are cumbersome, heavy, and expensive to repair. They are costly in the first instance, and they block up the rooms of the mill with large drums and pulleys, obstructing the light, which, in factories, is a consideration of very great importance.

At the commencement of the present century mills were geared with ponderous shafts, such as those just described. They were generally of cast iron, square, and badly coupled, and the power required to keep them in motion was in some cases almost equal to that required by the machinery they had to drive. In the present improved system, with light shafts accurately fitted and running at high velocities, the work which previously was absorbed in transmission is now conveyed to the machinery of the mill.

I may safely ascribe my own success in life and that of my friend and late partner, Mr. James Lillie, to the saving of power effected by increasing threefold the velocity of the shafting in mills more than forty years ago. The introduction of light iron shafting not only enabled the manufacturer to effect a considerable saving in the original cost, but a still greater saving was

effected in power, whilst it relieved the mills from the ponderous wooden drums and heavy shafting then in use, and established an entirely new system of operations in the machinery of transmission.

5. *Length of Journals.**

Another consideration of considerable importance to the smooth and safe working of shafting is the length of the journals. From a number of years' experience I have been led to believe, that with cast iron, one and a half times the diameter of the shaft is the best proportion for the length of the bearing, and with wrought iron, one and three quarters the diameter. On the question of shafts revolving in the steps of plummer-blocks and the proportions necessary to effect motion without danger of heating, it is essential (without entering largely into the laws of friction on bodies in contact) that we should ascertain from actual practice and long-tried experience the best form of journals of shafts adapted for that purpose. The lengths proportionate to the diameters have already been given, but we have yet to consider the dimensions of the journals of large shafts where they are small in comparison with the pressure or the weight they have to sustain. Let us, for example, take a fly-wheel shaft and the foot or toe of a line of vertical shaft extending to a height of six or seven stories in a mill filled with machinery, and we have the safe working pressure per square inch as indicated in the last column in the following table:—

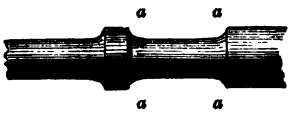
Description of Shaft	Length and diameter of Shaft in ins.	Number of square inches in bearing	Weight on bearing in lbs.	Weight in lbs. per square inch on bearing
Fly-wheel shaft wrought iron	18 × 14	252	45,024	178·21
Vertical shaft cast iron .	— × 11	95	23,061	242·70
Horizontal shaft cast iron .	15 × 10	150	6,000	40·00
Horizontal shaft wrought iron	6 × 3	18	540	30·00
Ditto ditto ditto .	2 × 4	8	160	20·00

From the above it will be seen that in fly-wheel shafts the

* Rules for the diameters of gudgeons or journals for those cases in which they are calculated independently of the diameter of the shaft, are given in Mills and Millwork, Second Edition, Part I., p. 119.

pressure should never exceed 180 lbs. per square inch, and in that of the toes of vertical shafts 240 lbs. per square inch. Even with this latter pressure it is difficult to keep the shafts cool, and it requires the greatest possible care to keep them free from dust or any minute particles of sand or other sharp substances getting into the steps. The feet of vertical shafts also require the very best quality of gun metal for the shaft to run in, and fine limpid oil for lubrication to prevent the toe from cutting. It is, moreover, necessary for the shaft to fit well on the bottom of the step, and not too tight on the sides, and to have a fine polish.

Fig. 206.



Another point for consideration is the proper form of the journals of shafts, and that is, they should never have the journal turned or cut square down to the diameter, but hollowed in the form shown in the figure at *a a a a*. From a series of interesting experiments it has been shown that the square-cut shaft loses nearly $\frac{1}{3}$th of its strength, and by simply curving out the shaft at the collars in the form described, the resistance to strain is increased $\frac{1}{3}$th, or in that proportion.

6. *Friction.*

On the subject of friction much cannot be said. We may, however, adduce a few experiments from Morin and Rivière, which appear to bear out our previous experience of the length of journals.

In the years 1831, 1832, and 1833, a very extensive set of experiments were made at Metz by M. Morin, under the sanction of the French Government, to determine, as nearly as possible, the laws of friction, and by which the following were fully established:—

When no unguent is interposed, the friction of any two surfaces, whether of quiescence or of motion, is directly proportional to the force with which they are pressed perpendicularly together; so that for any two given surfaces of contact there is a constant ratio of the friction to the perpendicular pressure of the one surface upon the other. Whilst this ratio is thus the same for the same surfaces of contact, it is different for different

surfaces of contact. The particular value of it in respect to any two given surfaces of contact, is called the coefficient of friction in respect to those surfaces.

When no unguent is interposed, the amount of the friction is, in every case, wholly independent of the extent of the surfaces of contact; so that the force with which two surfaces are pressed together, being the same, their friction is the same, whatever be the extent of their surfaces of contact.

That the friction of motion is wholly independent of the velocity of the motion.

That where unguents are interposed, the coefficient of friction depends upon the nature of the unguent, and upon the greater or less abundance of the supply. In respect to the supply of the unguent, there are two extreme cases,—that in which the surfaces of contact are but slightly rubbed with the unctuous matter, as, for instance, with an oiled or greasy cloth, and that in which a continuous stratum of unguent remains continually interposed between the moving surfaces; and in this state the amount of friction is found to be dependent rather upon the nature of the unguent than upon that of the surfaces of contact. M. Morin found that with unguents (hog's lard and olive oil) interposed in a continuous stratum between surfaces of wood on metal, wood on wood, and metal on metal, when in motion, have all of them very nearly the same coefficient of friction, being in all cases included between ·07 and ·08. The coefficient for the unguent tallow is the same, except in that of metals upon metals. This unguent appears to be less suited for metallic surfaces than the others, and gives for the mean value of its coefficient under the same circumstances ·10. Hence it is evident that where the extent of the surface sustaining a given pressure is so great as to make the pressure less than that which corresponds to a state of perfect separation, this greater extent of surface tends to increase the friction by reason of that adhesiveness of the unguent, dependent upon its greater or less viscosity, whose effect is proportional to the extent of the surfaces between which it is interposed.

Mr. G. Rennie found, from a mean of experiments with different unguents on axles in motion, and under different pressures, that with the unguent tallow, under a pressure of from 1 to

5 cwt., the friction did not exceed $\frac{1}{39}$th of the whole pressure; when soft soap was applied it became $\frac{1}{34}$th; and with the softer unguents applied, such as oil, hog's lard, &c., the ratio of the friction to the pressure increased; but with the harder unguents, as soft soap, tallow, and anti-attrition composition, the friction considerably diminished: consequently, to secure effective lubrication, the nature of the unguent must be accommodated to the pressure or weight tending to force the surfaces together.

TABLE OF COEFFICIENTS OF FRICTION UNDER PRESSURES INCREASED CONTINUALLY UP TO LIMITS OF ABRASION. BY MR. G. RENNIE.

Pressures per Square Inch	Coefficients of Friction			
	Wrought Iron upon Wrought Iron	Wrought Iron upon Cast Iron	Steel upon Cast Iron	Brass upon Cast Iron
32·5 lbs.	·140	·174	·166	·157
1·66 cwts.	·250	·275	·300	·225
2·00 „	·271	·292	·333	·219
2·33 „	·285	·321	·340	·214
2·66 „	·297	·329	·344	·211
3·00 „	·312	·333	·347	·215
3·33 „	·350	·351	·351	·206
3·66 „	·376	·353	·353	·205
4·00 „	·395	·365	·354	·208
4·33 „	·403	·366	·356	·221
4·66 „	·409	·366	·357	·223
5·00 „	—	·367	·358	·233
5·33 „	—	·367	·359	·234
5·66 „	—	·367	·367	·235
6·00 „	—	·376	·403	·233
6·33 „	—	·434	—	·234
6·66 „	—	—	—	·235
7·00 „	—	—	—	·232
7·33 „	—	—	—	·273

From a paper lately read at the Institution of Civil Engineers in London, on the comparative friction of steam engines of different modifications, it appears that, as respects the friction caused by the strain, if the beam engine be taken as the standard of comparison—

The vibrating engine . . has a gain of 1·1 per cent.
The direct engine with slides „ loss of 1·8 „
Ditto with rollers . . „ gain of 0·8 „
Ditto with a parallel motion „ gain of 1·3 „

It also states, as an opinion, that excessive allowance for friction has hitherto been made in calculating the effective power of engines in general; as it is found practically by experiments with the engines at the Blackwall Railway, and also with other engines, that where the pressure upon the piston is about 12 lbs. per square inch, the friction does not amount to more than $1\frac{1}{2}$ lbs.; and also that by experiments with an indicator on an engine of 50 horse-power, at Truman, Hanbury, and Co.'s brewery, the whole amount of friction did not exceed 5 horse-power, or $\frac{1}{10}$th of the whole power of the engine.

7. *Lubrication.*

On this question it is necessary to observe that the durability of shafts, and their easy working, depends on the way in which they are lubricated, and the description of unguent used for that purpose. We have already seen the difference which exists in the coefficient of friction from the use of different kinds of unguents, and we have now to consider what system of lubrication should be adopted to lessen the friction and maintain smooth surfaces on the journals of shafts. In large cotton mills I have known as much as ten to fifteen horses' power absorbed by a change in the quality of the oil used for lubrication; and in cold weather, or when the temperature of the mill is much reduced (as is generally the case when standing over Sunday), the power required on a Monday morning is invariably greater than at any other time during the week.

It is, therefore, necessary in most mills—particularly those employed in textile manufacture—to retain a uniform temperature, and to employ the best quality of oil for lubricating the machinery, as well as the shafts of the mill.

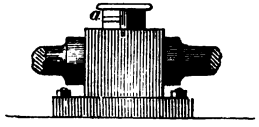
The best lubricators are pure sperm and olive oils; they should be clean and limpid, and sparingly applied, as it is a profligate waste of valuable material to pour, as is not unfrequently done, large quantities of oil on the bearings, nine-tenths of which run on to the floor, and cover the shafts and hangers with a coat of glutinous matter, that soon hardens, and accumulates nothing but filth.

This process of oiling shafts is generally left to the most negligent and most untidy person in the establishment; and

the result is, that every opening for the oil to get to the bearings is plugged up, the brass steps are cut by abrasion, and the necks or journals of the shafts destroyed. In the best-regulated establishments this is certainly not the case, as the greatest possible care is observed in selecting the best kinds of oil, and that used with attention to cleanliness and strict economy in its application.

To save power and effect economy in the use of lubricants, several schemes have been adopted for attaining a continuous system of lubrication. None of them appears to answer so well as that which consists of a small cistern, *a*, fig. 207, which contains a quantity of oil, and is fixed on the top of the plummer-block. In the centre of the cistern is a tube, which stands a little above the level of the oil; and into this is inserted a woollen thread, with its end descending a short distance below the surface of the oil in the cistern; and when properly saturated, the oil rises by capillary attraction, and flows gently, in very minute quantities, on to the neck of the shaft. From this description it will be seen that the quantity used can be regulated to the greatest nicety, and sufficient to lubricate the bearings without waste. Other plans have been devised for the same object, but none of them seems to answer so well as that just described.

Fig. 207.



CHAPTER III.

ON COUPLINGS FOR SHAFTS AND ENGAGING AND DISENGAGING GEAR.

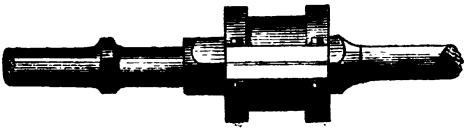
In every description of mill where the machinery is spread over a large area, and at a distance from the moving power, it is necessary to have long lines of shafting, revolving at the required velocity. Such lines are seldom made in one piece; short lengths must, therefore, be coupled together, so as to form an unbroken line, extending, in most cases, the whole length of the mill.

When cast-iron shafts were substituted for wood, a square coupling-box, made in one piece, was generally used, so as to slide over the two ends of the shafts, or in two pieces, bolted together, as shown in figs. 208 and 209.

Fig. 208.

In the former case the box was slipped on loose, and the adjustment was so imperfect that the shafts rose and fell in the box at every revolution, destroying gradually any accuracy of fitting which, in the first instance, had been attained.

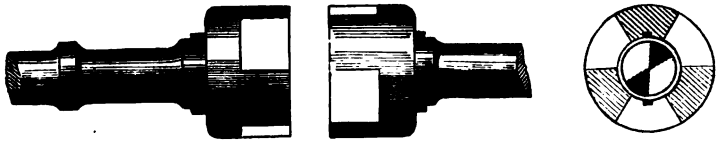
Fig. 209.



After the square-box coupling came the claw, or two-pronged coupling, made in two parts, wedged, but more frequently keyed

on to the ends of the shafts, as shown in fig. 210. This was a great improvement, as the leverage of the bearing parts was

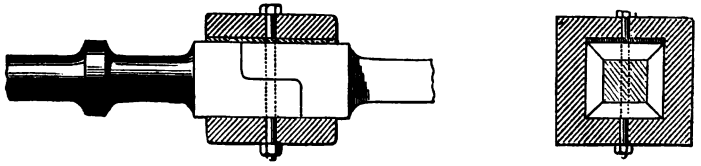
Fig. 210.



greatly increased, and the coupling, in consequence, became more durable.

A description of half-lap coupling was introduced by the late Mr. Hewes. It was formed by the lapping over a part of the end of each shaft, which was cast square. A square box was also fitted over the two ends, so as to bind them together, and *three* keys were inserted on the top side, as shown in fig. 211.

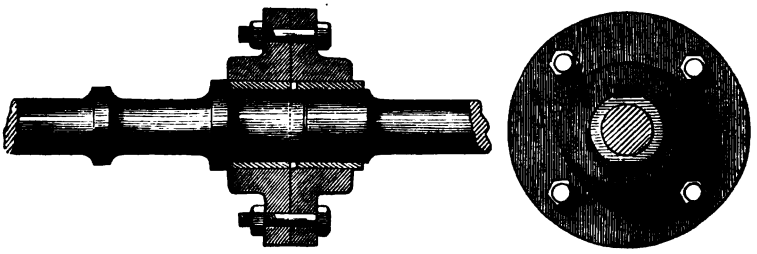
Fig. 211.



The objections to this coupling were the difficulty of fitting, and the loosening of the keys, which made a creaking noise with every revolution of the shaft.

Another coupling, still in use, is the disc. It consists of two discs or flanges, one on the end of each shaft, bolted together by four bolts, as shown in fig. 212. This coupling

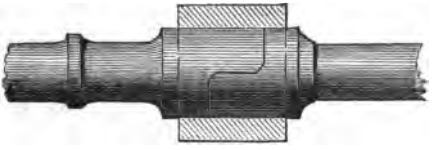
Fig. 212.



was superior to all the preceding, when properly bored and turned, so as to have its faces accurately perpendicular to the shafting.

The best coupling for general purposes and the most accurate and durable, is the circular half-lap coupling, introduced into my own works nearly forty years ago. It is perfectly round, and consists of two laps, turned to a gauge, and, when put together by a cutting machine, it forms a complete cylinder, as shown in fig. 213. A cylindrical box is fitted over these, and fixed by a

Fig. 213.



key, grooved half into the box and half into the shaft. The whole is then turned in the lathe to the same centres as the bearings of the shaft, and by this process a degree of accuracy is attained which cannot be surpassed, nor is any other coupling so neat and so well adapted for the transmission of power.

The proportions of this coupling are found by experiment to be—

Twice the area of the shaft is the area of the coupling.

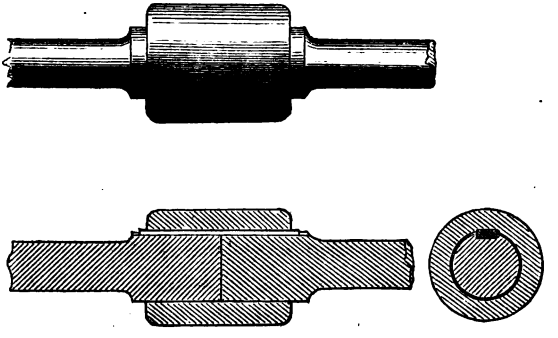
The length of the lap is the diameter of the shaft.

And the length of the box is twice the diameter of the shaft.

These proportions have been found in practice to answer every purpose, both as regards strength and the wear and tear of the joints.

There is another coupling which has come of late years extensively into use, namely, the cylindrical coupling, with butt ends. It has the same

Fig. 214.



proportions as the former, but not so strong nor so durable as the half-lap coupling of the same dimensions, as the entire force of torsion is transmitted through the key; but in cases where strength is not the chief object, it forms a cheap and effective coupling.

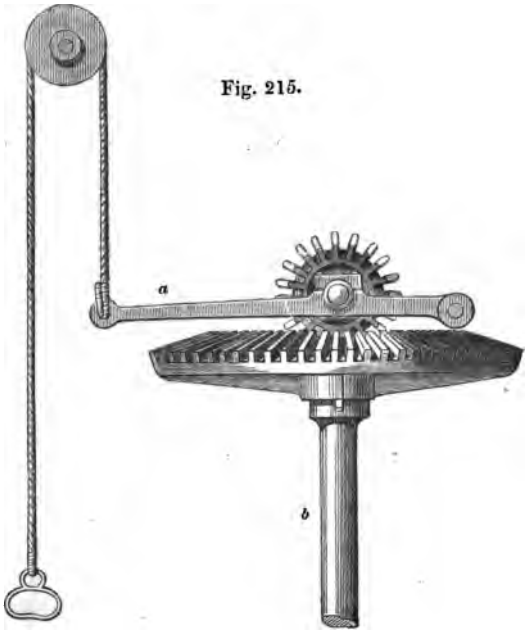
8. *Disengaging and re-engaging Gear.*

This is an important branch of mill-work, requiring careful consideration and the utmost exactitude of construction when ponderous machinery has to be started, without endangering the shafts and wheels. This is most strikingly exemplified in the case of powder mills, where trains of edge stones are employed for grinding the gunpowder, and in rolling and callendering machinery, which requires well-fitted friction-clutches to communicate the motion by a slow and progressive acceleration from a state of rest to the required velocity.

It used to be customary in cotton and silk mills to place disengaging clutches at the point of connection of the upright or driving shaft and the main shafting of each room, so that, in case of accident, a room full of machinery could be thrown out of gear at once. But these provisions were found unsteady in practice, and rather tended to increase than to diminish the number of accidents, owing chiefly to the time lost in disengaging, and the breakages which occurred in attempting to place the machinery in gear again, when the engine was running at full speed. It has, consequently, been found safer to have a permanent connection between the main lines of shafting throughout the mill, and signals from each room into the engine-house, in case of accident.

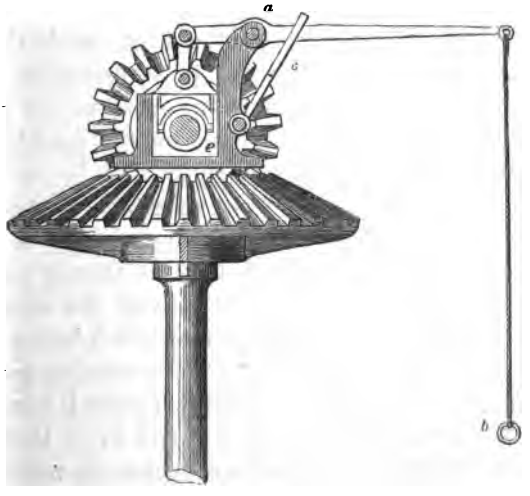
When the construction of mill gearing was less perfect than it is at present, the main shaft driving the machinery in a room was thrown out of gear by a lever, which contained the steps, and supported the end of the horizontal shaft and wheel, which geared into that on the upright shaft, as shown in fig. 215, with a rope at the end of the lever *a* to pull it out of gear. This mode of disengaging wheels was very ineffective, as in many mills there are three bevel wheels gearing into that on the upright *b*, and it becomes complicated and dangerous to have

Fig. 215.



movable levers to each. To remedy these defects, standards or plummer-blocks, with a movable slide *e*, fig. 216, in which the end of the shaft revolved, was introduced. To the top

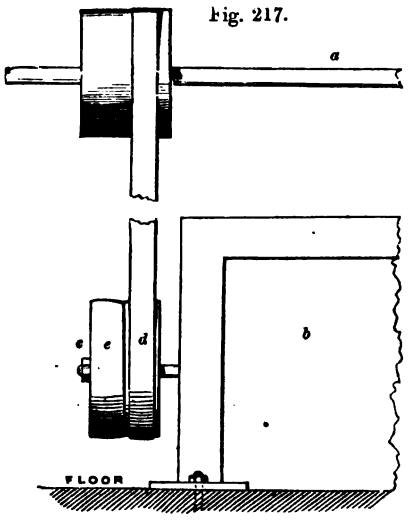
Fig. 216.



of this slide was attached a lever *a*, with a handle *b*, by which it could be drawn out of gear; and the link *c*, falling along with the lever, retained the shaft out of gear until the mill was stopped.

All these contrivances were, however, found inoperative on a large scale, as the shafts and wheels got out of order; and it was ultimately found essentially necessary to make them stationary, by screwing the plummer-block down to the frame which connects the shafts and wheels.

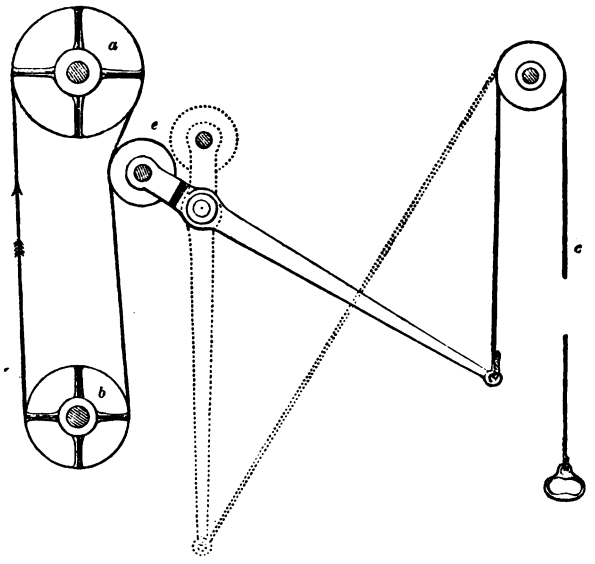
Fig. 217.



Several devices have been employed for the purpose of rapidly engaging and disengaging machines from the driving shaft. The best of all are the fast and loose pulleys, with a travelling strap. Thus, in fig. 217, *a* is the driving shaft, acting upon two pulleys *e* and *d*, fixed on the driving spindle of the machine *b*; one of them, *d*, is keyed fast, and the other runs loose. When the machine is at work the strap is on the fast pulley *d*, and when it is necessary to stop, it is moved by a forked lever on to the loose pulley *e*, which revolves with the strap without acting on the machine. The machine is thrown into gear with equal ease by moving the strap on to the fast pulley *d*. Once on either of the pulleys, the strap is held in position without any danger of moving by the slight curvature of the pulley, as already explained. The forked lever must act on that side of the strap which runs towards the pulleys, and not on that which leaves them.

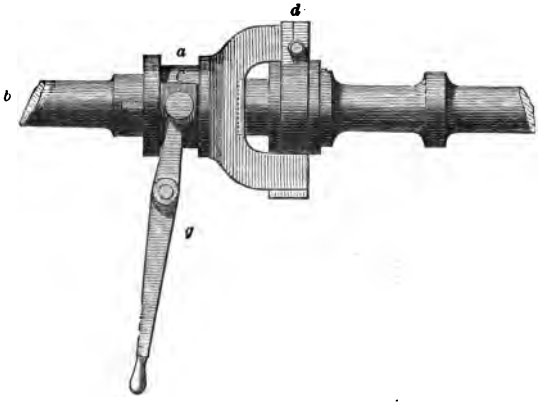
A second and equally effective process for starting or stopping machinery is shown in fig. 218. A leather strap is hung loosely over the driving and driven pulleys *a* and *b*, so that, left to itself, the friction is not sufficient to communicate motion to the

Fig. 218.



pulley on the shaft *b*; but a tightening pulley fixed on a suitable lever *e* is forced against it by pulling the rope *c*, which bends the strap tightly upon the pulley *b*, and gives motion to the machine. This arrangement is in general use for sack teagles in corn mills, and for some other purposes. The same effect is sometimes produced by the sack teagles being fixed on the lever, and, by raising one end, the strap is tightened, and the barrel which raises the load is caused to revolve.

Fig. 219.

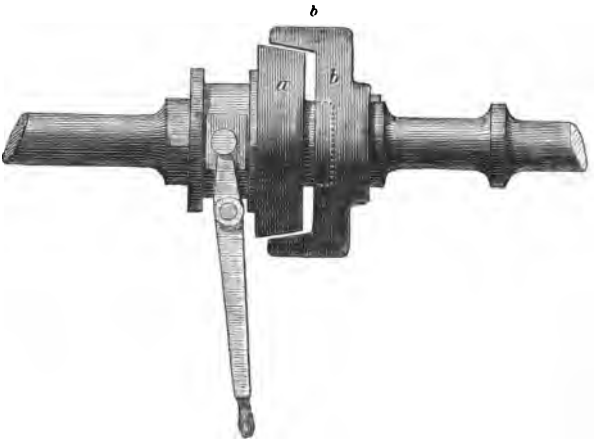


The clutch most in use for throwing into gear heavy calendering machines is a clip friction hoop, which consists

of a sliding box *a*, with two projecting horns on the driving shaft *b*. These horns, when slid forward by a lever *g*, working in the groove *c*, come in contact with the friction hoop *d*, which embraces a groove in a second box, keyed upon the shaft of the machine. The instant the machine receives the shock of engagement, the clip *d* slides in its groove, until the friction overcomes the resistance, and the callender attains the speed of the driving shaft. The object of the friction clip is to reduce the shock of throwing the clutch suddenly into gear, as without this precaution any attempt to move instantaneously a powerful machine from a state of rest to a state of motion would break it in pieces.

Friction cones are also much used for this purpose, and when carefully executed with the proper angle are safer than the clutch just described. The objection to the friction clutch is, that the whole driving power is thrown on the clip at once; whereas, with the cones, the parts can be brought into contact with the greatest nicety, and the friction regularly increased to any degree of pressure. Fig. 220 shows this description of disen-

Fig. 220.



gaging gear: *a* is the male sliding cone, worked by a lever in the usual way, *b* the female cone, keyed on the driven shaft, and the two surfaces, when brought into contact, communicate the required motion with perfect safety.

Machines driven by friction, and requiring to be frequently

stopped, are very numerous. Some of the lighter description are driven by a vertical shaft *b*, fig. 221, supporting a horizontal disc, which communicates motion to the wheel *a*, rolling on its surface, and gives the necessary motion to the machine. The advantage of this friction-wheel is, that the velocity of the machine may be increased or diminished at pleasure by moving the wheel *a* nearer to or farther from the edge of the disc.

Fig. 221.

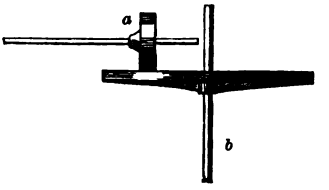
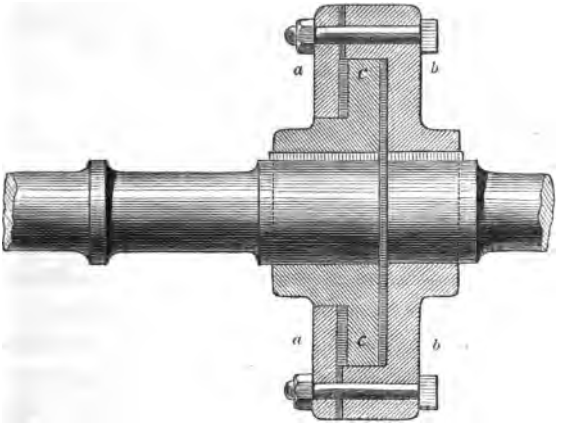


Fig. 222 is another combination of discs suitable for couplings with only one bearing. The disc *b* is keyed on one shaft, and is recessed on the face, to receive the smaller disc *c*; this disc is sunk flush with the face of the other, and is screwed tightly

Fig. 222.



up to it by means of the ring *a*, which is bolted to the disc *b*, and secures that marked *c*. Between the three plates, *a*, *b*, and *c*, annular pieces of leather are interposed, which bring them all to a proper bearing.

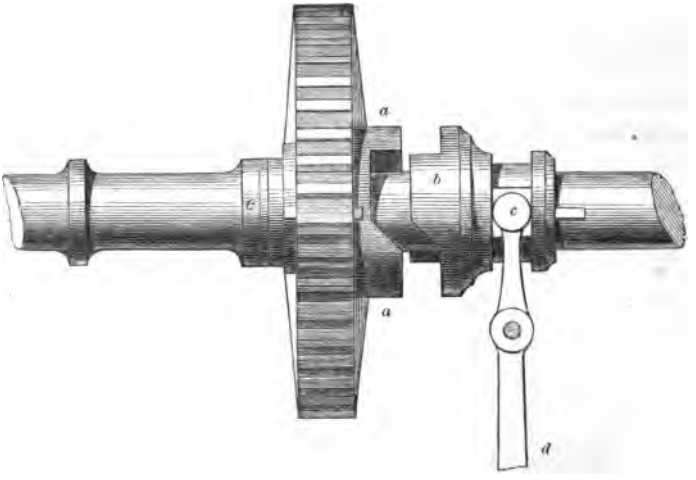
This combination, termed a friction coupling, is useful for preventing breakage of the connections in case of a sudden stoppage or reversal of the motion. It is plain that the holding power of the coupling depends simply upon the tightness with

which the discs are screwed together, and the consequent frictional force of the surfaces of leather and metal.

Besides these more permanent forms of couplings, there are other contrivances adopted when the object to be attained is the engagement and disengagement of certain parts of the machinery or gearing during the course of operations.

With the same view of admitting of this disengagement of the connection, in cases of sudden stoppage or reversal, the coupling, fig. 223, is sometimes employed.

Fig. 223.



In this instance, the shaft is supposed to be continuous, and the coupling may be termed a disengaging coupling. *a* and *b* are the two parts of the coupling, formed on the acting faces into alternate projections and recesses, such that they correspond with and exactly fit into each other when in gear. The part *a* is, in this example, cast on a spur or bevel wheel, from which the motion of the shaft is supposed to be taken off. Both of the parts *a* and *b* are, to a certain extent, loose on the shaft; the former being capable of moving round on it, though deprived of longitudinal motion by washers and a collar, marked *e*, and the latter being free to slide on the shaft, though prevented from turning on it by a sunk key, which slides in a slot inside the clutch or sliding piece *b*. The mechanism is put into gear by means of the lever *d*, which terminates in a fork with cylin-

drical extremities *c*; and it is obvious that, by the contact of the flat faces of *a* and *b*, the latter will immediately carry with it the other part at the same speed as the shaft. Supposing, now, that the motion of the wheel *a* is suddenly accelerated, the oblique faces of the couplings immediately fall out of contact, and slide free of each other, leaving the couplings clear, and the shaft free to continue in motion.

In the old form of this contrivance, known as the sliding bayonet clutch, the part *b*, instead of the toothlike projections on the face, had two or more prongs which laid hold of corresponding snugs cast on the face of the part *a*, which, moreover, was usually a broad belt pulley, introduced with a view to modify the shock on the gearing on throwing the clutch into action.

In an older form still, the pulley was made to slide end long on the shaft. A form analogous to this was known as the "lock pulley," a few specimens of which still remain in the older factories. Instead of the end long motion common to the other modes, the parts were "locked" together by a bolt fixed upon the side of the pulley, and which, when shifted towards the axis, engaged with an arm of a cross, of which the part *b*, in the preceding figure, is the modern representative. The bolt was wrought by means of a key and stop, the turning of the key throwing back the bolt, and thereby unlocking and disengaging the pulley. The form of coupling represented by fig. 223 is particularly applicable when the impelling power is derived from two sources—a circumstance which frequently occurs in localities affording water power to some extent, and yet not in sufficient abundance for the demands of the work. The deficiency is usually supplied by a steam engine; and the two powers are concentrated in the main line of shafting by a coupling of the kind depicted. In cases of this kind, the speed of the shafting being fixed, and the supply of water inconstant, the power of the water-wheel ought to be thrown upon the wheel *a a*, and that of the engine upon the shaft at another point. By this arrangement, the speed of the line can be exactly regulated by working the engine to a greater or less power, according to the supply of water. The proper speed of the water-wheel will likewise be maintained, which is of importance in economising the water power.

"The same form of coupling is also used occasionally for engaging and disengaging portions of the machinery. But for this purpose the object is to obtain a mode of connection by which the motion may be commenced without shock; for, in consequence of the inertia of all material things—that is, the tendency which every portion of matter has, when at rest, to remain at rest, and when in motion, to continue to move—the parts of the mechanism, when acted upon too suddenly by a moving power, are liable to fracture and disarrangement. It is a law in mechanics that when a body is struck by another in motion some time elapses before it is diffused from the point struck through the other parts; consequently, if the parts receiving the blow have not sufficient elasticity and cohesive force to absorb the whole momentum of the striking body till the motion be transmitted to the centre of rotation, fracture of the body struck must necessarily ensue. Hence, in a system of mechanism, any parts intended to be acted upon suddenly by others in full motion ought not only to be strong, but they ought to be capable of yielding on the first impulse of the impelling force with as little resistance as possible, and gradually bring the whole weight into motion. The common mode of driving by belts and pulleys accomplishes this object very satisfactorily. In this the elasticity of the belt comes into action; and being thrown upon the pulley by the strap guide or fork, it continues to slip, till, by the friction between the sliding surfaces, the belt gradually brings the quiescent pulley into full motion. This mode of connection is unexceptional when the power to be transferred is not great; but its application to large machinery is attended with inconvenience." *

In figs. 224, 225, two other forms of clutches are shown, as often used to connect the shafting of different parts of the same mill, where it is not necessary to throw into or out of gear when running at full speed. They consist of a fixed and sliding box, one on each shaft, with teeth or projections which fit in corresponding notches. The sliding box has a groove turned in it, in which a forked lever works, as at *a* (fig. 224) and at *a* (fig. 225), by which it is drawn backwards or forwards as the case may be. The peculiarity of the clutch (fig. 225) is that of

* Extract from Engineer's and Machinist's Assistant, p. 144.

the driving shaft, which, reversed by any accident in its motion, as is not unfrequently the case in starting and stopping the steam engine, the sliding clutch is forced back by the wedge-shaped faces of the projections, and the machinery thrown out of gear.

Fig. 224.

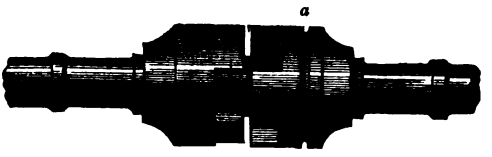


Fig. 225.

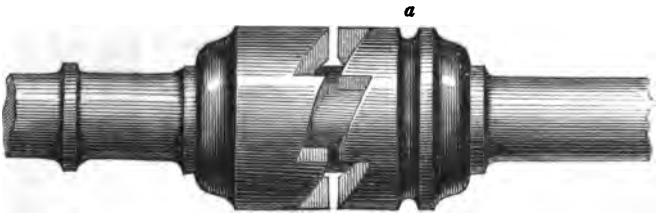
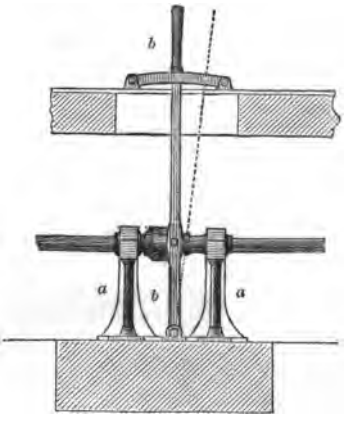


Fig. 226 shows one of these clutches on a small scale, fixed on a line of shafting beneath the floor of a mill. It is placed between two standards *a a*, supporting the ends of the shaft, and the lever *b* working on a pivot at bottom, and having a pin working in the groove of the sliding clutch box, serves for throwing the driven shaft into or out of gear whenever it may be necessary.

Fig. 226.



Another ingenious contrivance, I believe invented by Mr. Bodmer, is shown in figs. 227 and 228. It consists of a box *a a* running loosely on the driving shaft *s s*, but carrying the bevel wheel *b b*, which gears into another wheel on the driven shaft, not shown in the figures. Tightly keyed on the driving shaft *s s* is a boss *c c*, with two trunnions, on which slide two friction sectors *k k*; the outer

surface is coated with a copper plate, accurately fitting the interior surface of the running box *a a*. The boss *c c* carries

Fig. 227.

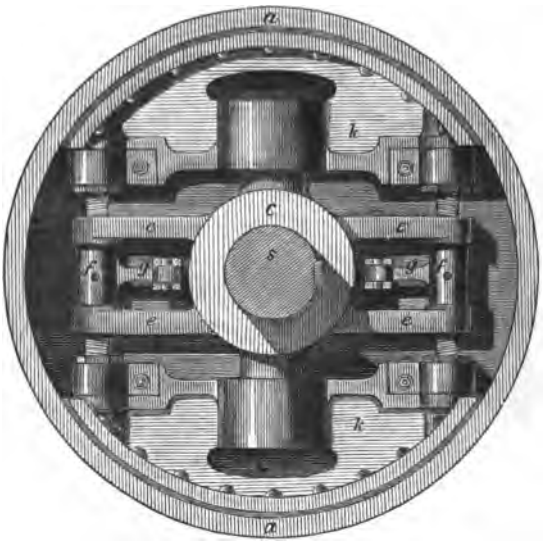
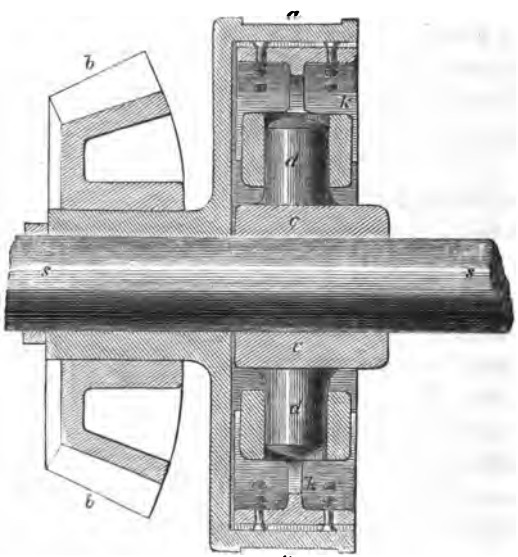


Fig. 228.



also four projections *e e e e*, which serve as guides for four screws, alternately left and right handed, and attached to the nuts *f f* and levers *g g*; these screws act on the extremities of the friction slides *k k*, so that when the levers *g g* are drawn back they are both with equal pressure forced upon the inner surface of the box *a a*. As the pressure can be very regularly and gradually brought on this box through the levers and screws, the motion of the driving shaft *s s* is communicated with perfect regularity, and without shock, to the bevel wheel *b b*.

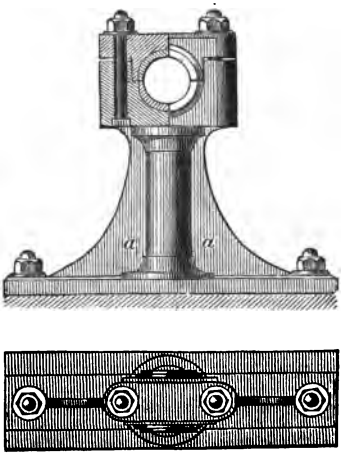
In the above description I have given such examples of engaging and disengaging gear as are most commonly in use. Others of a more complicated character might be cited, but they are not to be recommended as applicable in general practice. The last form, figs. 227 and 228, is, however, specially noticed as suitable for gunpowder mills, where the greatest possible freedom from shocks is essentially necessary.

9. *Hangers, Plummer-blocks, &c., for carrying Shafting.*

Shafting is supported in three ways, viz. on foundation stones in the floor, beneath beams suspended from the ceiling, and to the walls of the mill. This necessitates as many different forms of framework, known as hangers, plummer-blocks, standards, &c.

The simplest mode of supporting a range of light shafting is from the floor, and a pedestal suitable for this purpose is shown in fig. 229. It consists of a cast-iron base plate and column, with deep wings *a a* cast on to strengthen it free from vibration. The upper portion is hollowed out to receive the lower brass step, and the cap carrying the upper step. When the entire pressure of the shafting is downwards the upper brass bush is omitted, and the cap is cast

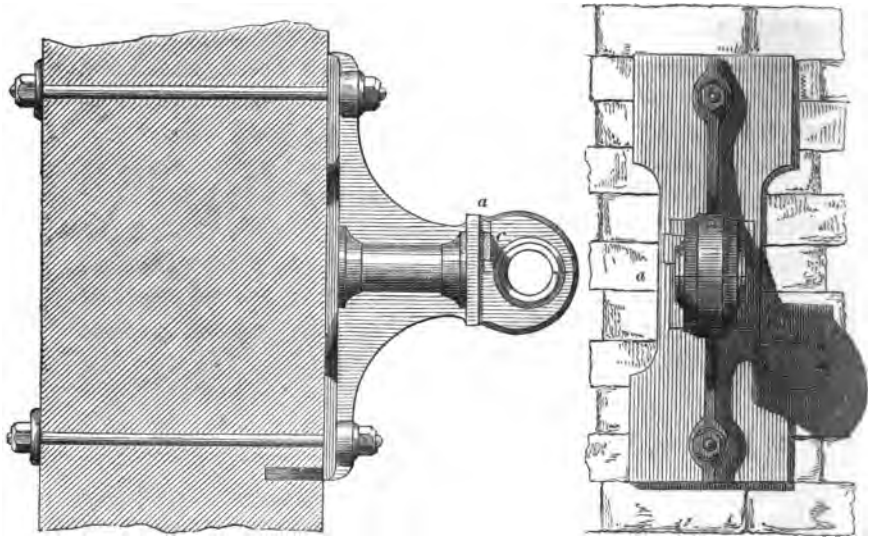
Fig. 229.



hollow and kept full of grease, so as to secure the most perfect lubrication of the journal of the shaft.

Fig. 230 shows a pedestal for bolting to a wall, the chief

Fig. 230.



difference being that the cap is now fixed on its inner side by a wedge or cotter (*c*). In this figure a shell cap *a* is shown. If the pull is upwards, and two brasses be required, "lugs" have to be added to the extremity of the pedestal and cap for bolting the two together.

There are various ways of suspending ranges of shafting from the ceiling, according to the means which exist for their attachment. If wooden beams, as s, are present, the hanger has a large plate (*a*), which bolts to the side of the beam, as shown in figs. 231, 232. The caps are fixed by a cotter, as in the previous case.

Figs. 233, 234 show a front and side elevation of another form of hanger for attachment to wooden beams. In this case there is provision for a second line of shafting, at right angles to, and receiving motion from, the primary line. For this purpose a small plummer-block is bolted on to a recess at the side of the hanger. The thrust, owing to the pair of bevel wheels

which would be placed near this hanger, is no longer simply vertical, and hence two brass steps are placed for the journal of the

Fig. 231.

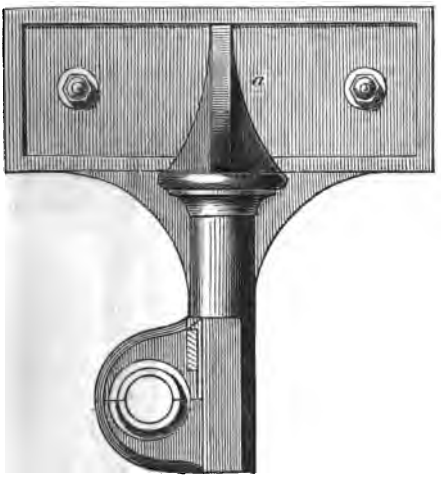


Fig. 232.

principal shaft, with a bolt at *d*, fig. 233, in addition to the cotter, to keep the cap in its place.

Fig. 233.

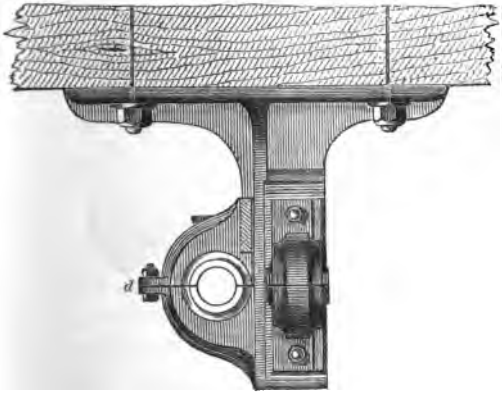


Fig. 234.

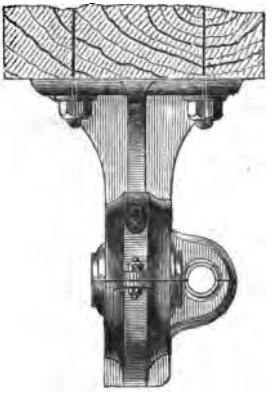


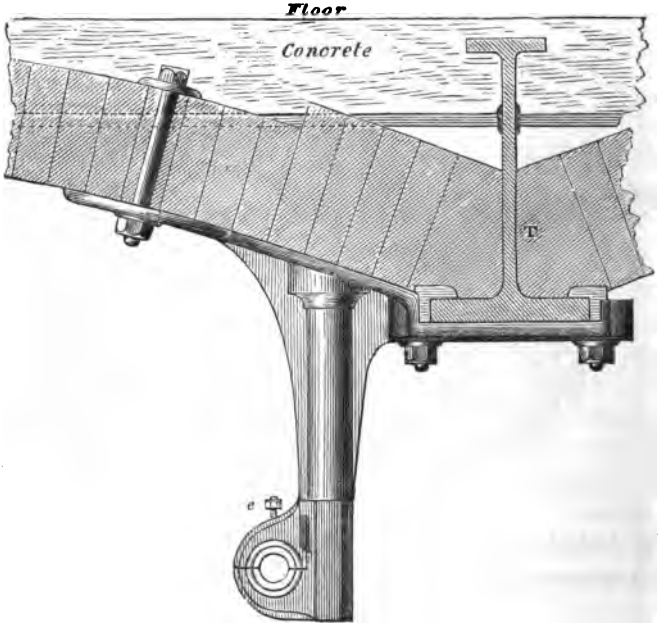
Fig. 235 shows another form of light hanger sometimes employed in weaving sheds, and also in use for supporting shafts

in fire-proof mills, being bolted up to the under side of the cast-iron beams, as shown at fig. 237.

Fig. 235.

Fig. 236.

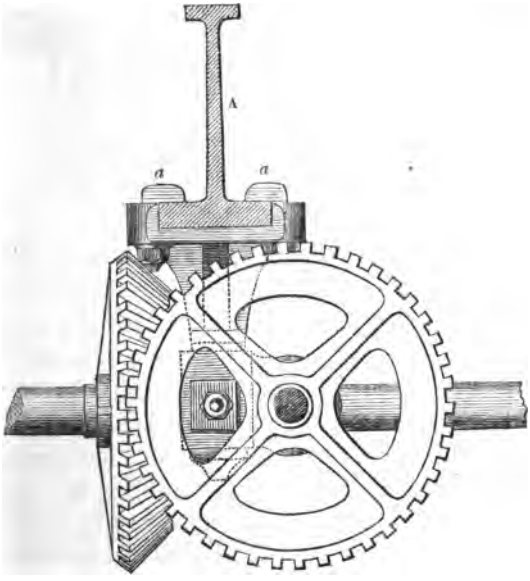
Fig. 237.



Where greater strength and firmness are required, especially in long hangers in which there is considerable leverage, the arrangement shown in figs. 236, 237 is adopted; the hanger in this case is bolted to a cast-iron beam, and by an extension of the flange plate to the brick arch, which springs from the beam T, it is firmly secured to both beam and floor. At *e* is a screw for tightening the upper brass step on the shaft.

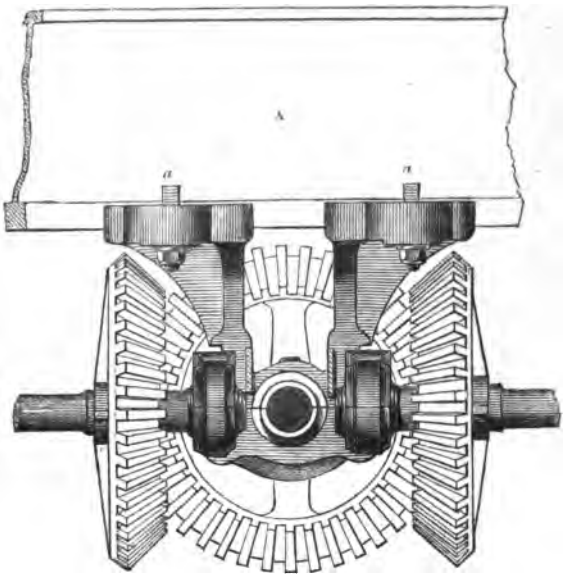
More complicated arrangements are sometimes necessary where two or three ranges of shafting have to be brought in connection with each other by means of bevel or mitre wheels. Figs. 238 and 239 show a front and side elevation of this

Fig. 238.



arrangement, which may serve as a type for others. The hanger is attached to a cast-iron beam A, by hooked bolts with nuts beneath the top plate, as shown at *a a*, *care being taken in this attachment not to weaken the flange of the iron beam by boring holes in it.* Double brass steps are necessary in this case for the main line of shafting, and also for two smaller ranges at right angles to it, which revolve in opposite directions, as shown at fig. 239.

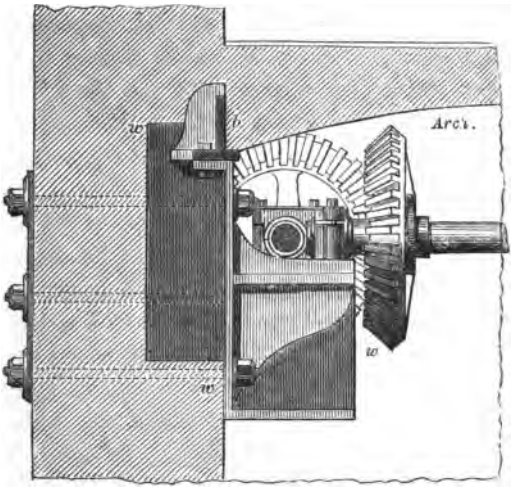
Fig. 239.



A very frequent case in practice is the connection of two ranges of shafting, at right angles to each other, at the corner of a room. This is effected by letting into the corner of the building a cast-iron frame, commonly known as a wall-box, which serves as a foundation for the plummer-blocks carrying the shafting. Such an arrangement is shown in fig. 240 in elevation, and in fig. 241 in plan. The box *w w w* is built into the wall, and bolted both to it and to the cast-iron beam *b*. It carries two plummer-blocks on a plate firmly supported by brackets. The wall pieces in these two figures are similar, but with a slightly different arrangement of the plummer-blocks.

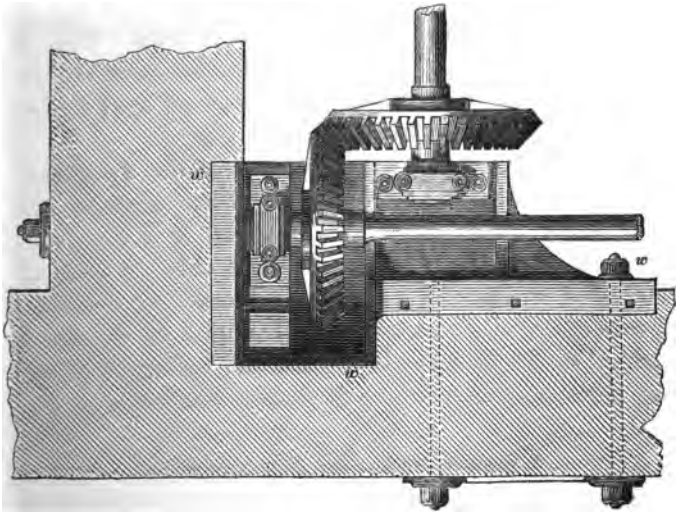
Irrespective of the various forms of engaging and disengaging apparatus, it will be necessary to consider the position, form, and proportions of the wheels and shafting required in mills where the power is divided and widely distributed. To show the enormous extent to which the concentration of machinery in one building has been carried, I may mention that in mills of my own construction there have been on the average not less

Fig. 240.



than 450 wheels and 7,000 feet of shafting in motion. In the large mills at Saltaire there are upwards of 600 wheels and 10,000 feet, or two miles, of shafting distributed over an area of

Fig. 241. (Plan.)



flooring equivalent to 12 acres. In corn mills and iron works, where the machinery is more closely connected with the prime mover, these considerations are of less importance; but in factories for the manufacture of textile fabrics the machinery covers a great extent of surface, and the greatest care is necessary in giving due proportion to the transmissive machinery, in order to secure uniformity of motion at the remotest parts of the mill.

In gearing a mill, the first consideration is the power of the engines, the position of the machinery to be driven, and the strength, diameter, &c., of the first-motion shaft, and other requisites for the transmission of motion in a well-geared mill. It is upwards of twenty years since the fly-wheel was converted into a first motion, and a new system of transmitting the power of the steam engines to the machinery of the mill introduced. Previous to that time it was effected by large spur-wheels inside the mill, now it is taken direct from the circumference of the fly-wheel.* The advantage of this system was the abolishing of the cumbrous first-motion gearing; and the requisite velocity being already present in the fly-wheel, it was only necessary to cast it with teeth, and to take off the power by a suitable pinion at the level most convenient for the purposes of the mill.

In another place I have given general rules for the pitch, breadth, and strength of the teeth of wheels. The Table (p. 101), computed from examples which have occurred in my own practice, exhibits the best proportions of spur fly-wheels to secure durability of both wheel and pinion.

It will be observed that the diameters of the fly-wheels are not always proportionate to the power of the engines, nor yet to their respective velocities. In practice, it is impossible to maintain uniformity in this respect, as, in order to meet all the requirements of manufacture, it is necessary to deviate from fixed principles, and to approximate as near as circumstances will admit to the diameters, weights, and velocities of wheels, as may be found convenient to produce a maximum effect.

* Compare Part I., Prime Movers, page 254.

TABLE 9.—DIAMETERS, PITCH, VELOCITY, &c., OF SPUR FLY-WHEELS OF THE NEW CONSTRUCTION.

Nominal Power of Steam Engine Horse-power	Diameter of Fly-wheel Feet	Inches	Pitch in Inches	Breadth of Cog in Inches	Velocity of Pitch-line per Minute in Feet
Two 150 = 300	30	1½	4½	16	The velocities vary according to circumstances, from 1,250 to 1,650 feet per minute.
Single = 50	13	3¾	4⅜	12	
Two 100 = 200	24	5	4	14	
Two 80 = 160	23	4	4	14	
Two 80 = 160	22	4	4	14	
Single = 60	19	0½	3⅜	12	
Two 70 = 140	24	5	3¼	12	
Two 70 = 140	22	8¼	3¼	14	
Two 50 = 100	21	0	3¼	12	
Two 40 = 80	21	0	3¼	10	
Two 45 = 90	20	0	3¼	12	
Single = 50	18	2½	3¼	12	
Two 35 = 70	16	0¾	3¼	10	
Single = 40	17	10	3	10	
Two 25 = 50	13	10	3	10	
Single = 25	8	11½	3	12	
Two 20 = 40	15	6	2⅞	7	
Two 25 = 50	15	4½	2⅞	8	
Single 25	15	4½	2⅞	7	
Two 18 = 36	13	0	2⅞	8	
Single 15	10	0	2⅞	7	
Single 18	17	11	2	6	
Single 12	10	0	2	5	

Of late years, the speed of the piston of factory steam engines has been accelerated from 240 to 300, and in some cases to 350 feet per minute. This united to the increased pressure of steam nearly doubles the power of the engines to what they were thirty years ago. The standard speed of a Bolton and Watt 7 feet stroke engine previous to that date was seventeen and a half strokes per minute.

In closing this section of practical construction, I may state that the couplings, engaging and disengaging gear, including the different forms of hangers, fixings, &c., are taken from my own designs, first introduced as a substitute for the cumbrous attachments that were in general use previous to the years 1820 and 1823.

Having determined the diameter, speed, and strength of the fly-wheel, the next consideration is the material, diameter, &c.,

of the main shafts. These are usually of cast iron, and their diameters depending on the power transmitted through them, and the velocity at which they revolve, will be found by the tables and formulæ already given. The distribution of the power is usually effected by a vertical shaft, extending from the bottom room, through the various floors of the mill, to the top story; the power being taken off at each stage by a pair of bevel wheels. This arrangement, as shown in fig. 242, represents one engine-house with a section of part of one division of the mills at Saltaire; and this may be considered as a type of other mills adapted for spinning and similar purposes.

It will be observed that there are four divisions in the Saltaire mills—one for the preparatory process, one for the wool combing, another for the spinning, and a fourth for the weaving. All these are driven by four steam engines, each of 100 nominal horses' power, but collectively distributing a force through these different departments of upwards of 1,250 horses.

On referring to the drawings, figs. 242 and 243, which represent a cross and longitudinal section of the mill, it will be seen that the vertical shaft A A is driven direct from the fly-wheel by the horizontal shaft B, giving motion to the machinery in each room as it ascends. It is fixed on a solid pier of ashlar, as shown at fig. 244, page 106, and supported on strong cast-iron plates and bridgetrees, firmly secured by bolts to the foundations below. In each room it is securely fixed, by cast-iron frames and boxes, forming a recess for the bevel wheels into the wall which divides the engine-house and the rooms above from the mill. This wall is generally made strong and thick, with sufficient weight to resist the action of the wheels prepared to drive the main lines of horizontal shafts with a speed and force equivalent to the work done in each room. In the case of the Saltaire mills this is considerable; nearly 300 horses' power being distributed through the upright shaft alone, the remainder being carried off to the loom shed by a second wheel, working into the bevel wheel *a*, on the horizontal shaft B, but not shown in the drawing. It is important, in mills where powerful steam engines are employed, that the foundations and fixings to which the main shafts are attached should be of the most

Fig. 242.

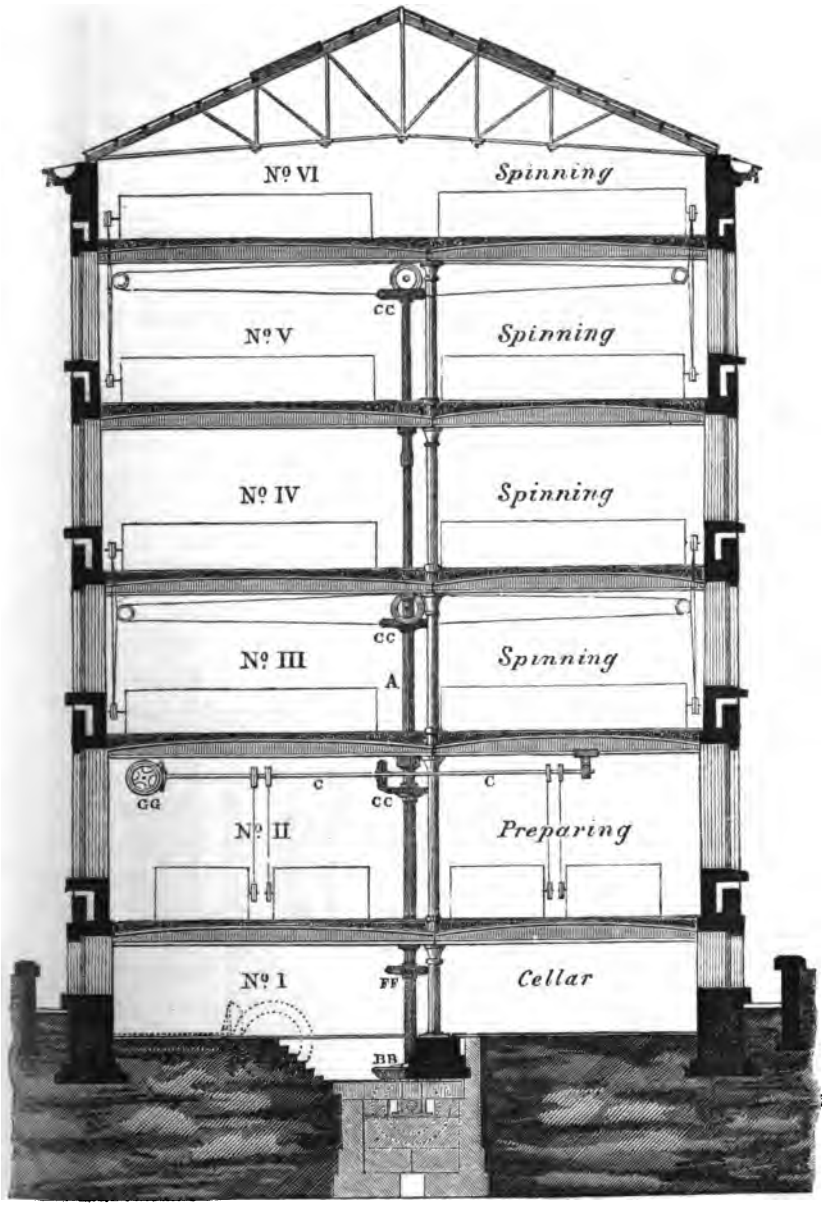
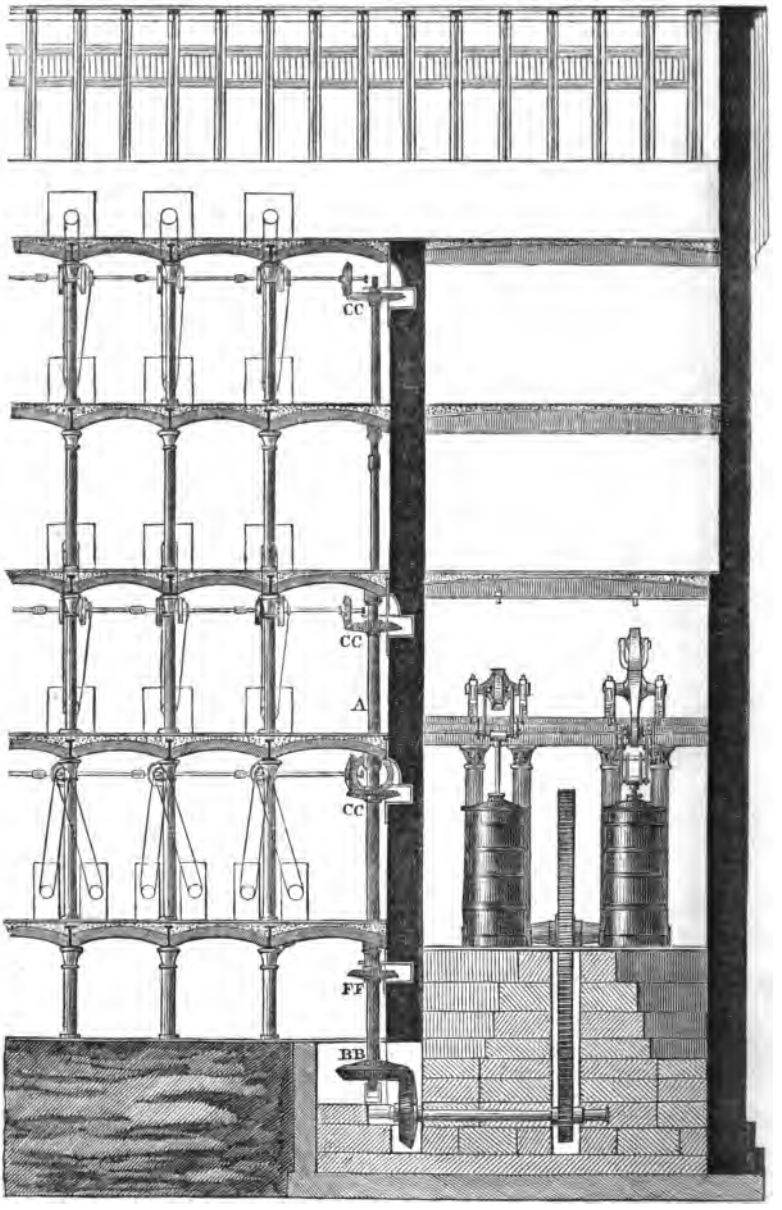

No VI
Spinning
CC
No V
Spinning
No IV
Spinning
CC
No III
A
Spinning
GG
C
CC
C
No II
Preparing
No I
FF
Cellar
BB

Fig. 243.



substantial description, and the greatest precaution is necessary in order to secure them from vibration, and to render them perfectly rigid when the whole force of the engines is applied.

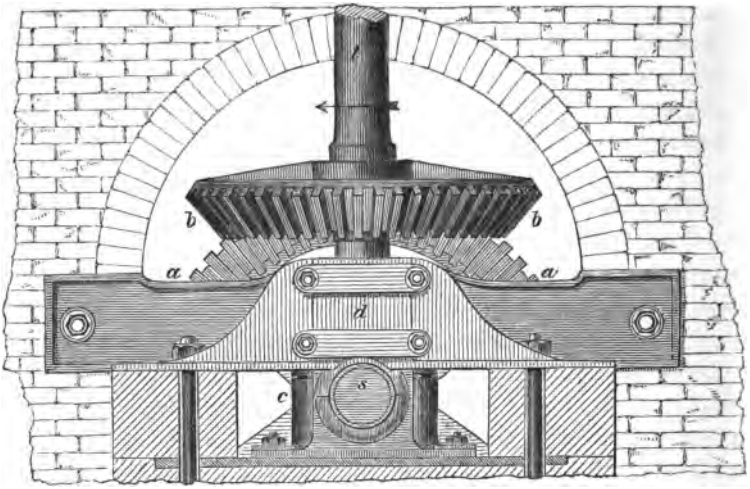
In the Saltaire mills, as in many others for the manufacture of cotton, flax, and wool, the preparatory machinery, such as carding, combing, roving, &c., is generally driven by lines of horizontal shafts, or by a series of cross shafts, branching off at right angles from the main line extending down the centre of the room, as shown at c c in No. II. room, fig. 242. Nos. III. and IV. rooms are driven by the longitudinal shaft in No. III.; and Nos. V. and VI. by the shaft in No. V. room. On this plan it will be noticed that the spinning machinery is driven by iron pulleys from the horizontal shafts, at a velocity of nearly 200 revolutions per minute, and the straps or belts from those pulleys are directed by means of guide pulleys to the machinery in both rooms. For this purpose, iron boxes are inserted into the arches supporting the floors, for the admission of the straps to the machinery in the upper floor.

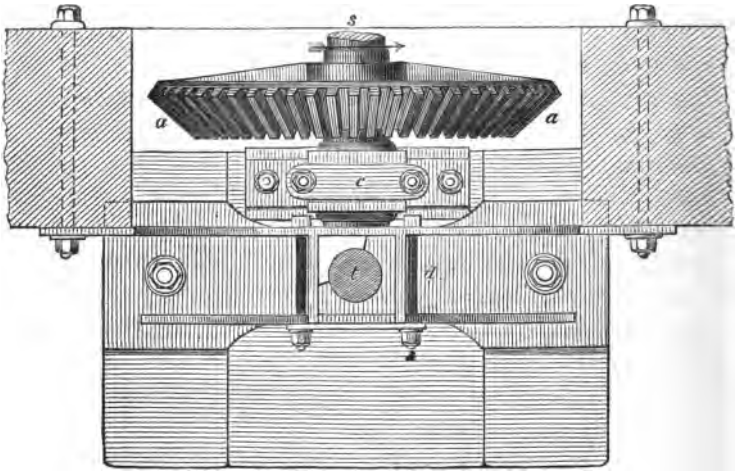
It will not be necessary to give the dimensions of the shafts in each room, as these details and calculations must be left to the judgment of the millwright, and the nature of the work they have to perform. Suffice it to observe, that the vertical shaft A is 10 inches diameter through the first two rooms, 8½ inches through the third room, and 6½ inches to the top; the velocity being 94 revolutions per minute.

As respects the couplings for this shaft, we may refer the reader to the Table of Dimensions (page 109) made from couplings actually in use, and which have been found, by experiment, serviceable in every case where strength and durability are required.

Great trouble is sometimes experienced with the foot of the vertical shaft, which, from its weight and the great pressure upon it, has a tendency to heat, unless sufficient bearing-area is allowed and the parts kept thoroughly lubricated. The general arrangements of the footsteps and gearing in large mills are shown in fig. 244: *s s* is the first-motion shaft, and *t t* the vertical shaft; *a a* the bevel wheel on the former, and *b b* the bevel wheel on the latter; *c* a plummer-block for the first-motion

Fig. 244.





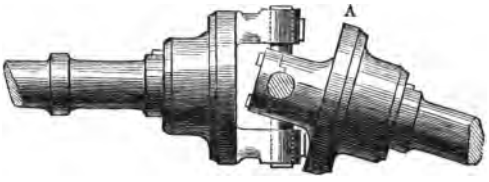
shaft, and *d d* the box containing the brass footstep for the vertical shaft: this box rests on a large base plate, bolted to the foundation stones and to the wall of the engine-house. In order to insure a constant supply of oil to the bearing, it is usual to cut away nearly the whole depth of the footstep, or that portion of the brass in the corner opposite to the thrust of the bevel wheels, as shown in the plan, fig. 244; this cavity is then kept full of oil, and lubricates the shaft throughout at every revolution.* Again, in cotton, woollen, and flax mills, when the first motion and vertical shafts have been duly proportioned to the work they have to perform, it becomes necessary to consider the diameter, speeds, &c., of the light shafting for driving the machinery in the different rooms. The formula given for strength, &c., in a former part of this work, will apply to this description of gearing and mill-work where the length does not exceed 120 feet. In long ranges of shafts, of from 150 to 200 feet in length, where the power applied to the machinery at the end of the room is considerable, it is essentially necessary to increase their strengths in order to prevent torsion or twist. This is a consideration of much importance, and requires careful attention, as long ranges of light shafts are very elastic—they, in some cases, effect nearly a complete revolution at the point of imparted motion before the extreme ends begin to move. The result of the power so irregularly transmitted by the spring of the shafts, resolves itself into a series of accelerated and retarded motions through the whole line of shafts, and imparts to the machinery in one-half of the room a very variable motion. Want of stiffness is a great evil in long lines of shafting, and, as we have already observed, instances are not wanting in which whole lines have been removed entirely from this cause.

The transmission of power to machinery placed at different angles from the line of shafts, which is sometimes the case in old mills, has generally been effected by the universal joint A,

* The reader may compare what is here said of footsteps with that in Part I. second edition, pp. 171, 175, on the steps for turbine shafts.

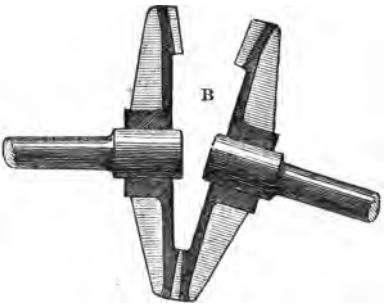
fig. 245, which works moderately well at an obtuse angle, but I have always found in my own practice that bevel wheels, as

Fig. 245.



at B, fig. 246, are preferable and more satisfactory. They give much less trouble, and work with greater ease, than the universal joint. Other examples might be given for the guidance of the practical millwright; but, having to discuss these points

Fig. 246.



at greater length when we come to treat of the different kinds of mills and different methods of gearing, we must direct the reader to those portions of the work which concern his own immediate practice.

The following Table exhibits the diameter of shafts, length of journals, diameter and proportions of couplings, &c., derived from actual practice, which may be useful to the less experienced millwright and engineer:—

TABLE 10.—LENGTH, DIAMETER, &c., OF COUPLINGS, COUPLING-BOXES, &c.

Diameter of Shaft	Length of Neck	Diameter of Coupling	Length of Lap	Length of Box	Diameter of Box	Thickness of Metal
1½ and 1⅝	3	2½	2	4½	4¼	⅞
1¾	3¼	3	2¼	5	5	1
2	4	3¼	2¼	5½	5½	1⅛
2¼	4½	3½	2¾	6	6	1¼
2½	5	4	3	6½	6¾	1⅜
2¾	5	4½	3¼	7	7½	1½
3	5½	4¾	3½	7½	7¾	1½
3¼	6¼	5	3¾	8	8¼	1⅝
3½	6½	5½	3¾	8¼	8¾	1⅝
4	7	6	4	8½	9½	1¾
4½	7½	6½	4½	9	10½	2
5	8	7¼	5	10	11¼	2
5½	8½	8	5½	11	12¼	2⅛
6	9	9	6	12	13½	2¼
6½	9½	9¾	6½	13	14¾	2½
7	10¼	10½	7	14	16	2¾
7½	11¼	11¼	7½	15	17	2⅞
8	12	12	8	16½	18	3
8½	12½	12½	8½	17	19	3¼
9	13½	13	9	18	20	3½
9½	14	13½	9½	18	21	3⅝
10	14½	14	10	18½	22¾	3¾
11	15	16	11	20	24	4
12	16	17½	12	21	26	4¼
13	17	18½	13	22	27½	4½

SECTION V.

ON MILL ARCHITECTURE.

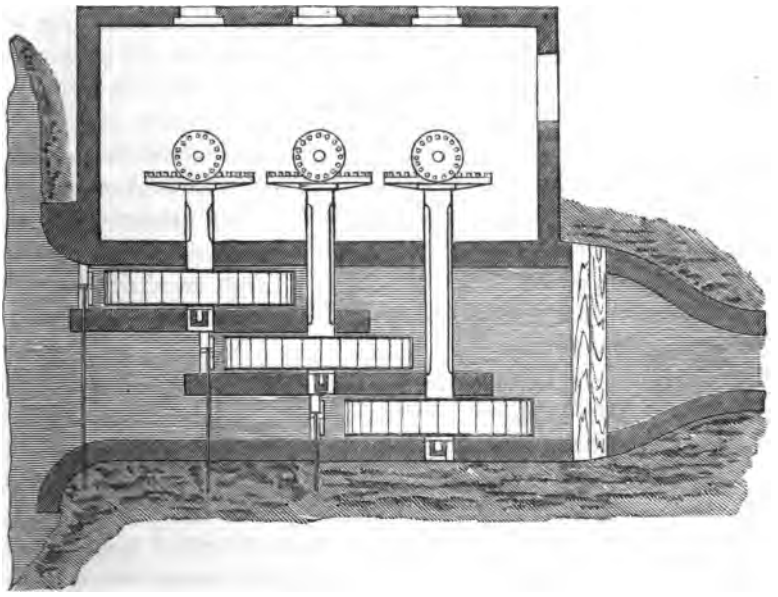
CHAPTER I.

ANCIENT AND MODERN MILLS.

In the early stages of civilisation, when industrial progress was at a low ebb, and in those days when the whole population was trained to war, and a miserable system of tillage existed, mills were little in demand, with the exception of corn and fulling mills; the former to grind oats and barley, and the latter to mill a rough description of serge or blanket. At that period, mill architecture was out of the question, as the dwellings of the retainers, and those employed in the field or manufactory, were mere hovels, and the architecture of the country was confined to churches, public buildings, and the mansions of the barons or lords of the soil. In such a state of society mills were simply sheds, with water-wheels having straight floats, and a long conduit or spout to carry the force of the water descending from the higher fall against the float-boards below. In process of time, as the population increased in numbers and intelligence, new demands for food and clothing were created, and a new description of mills was introduced to meet the requirements of a superior class to those under the feudal system, who were chiefly engaged in war and plunder. At this period mills were improved and enlarged, but there were no attempts at architecture; and, what is still more surprising, the engineers and millwrights of those days appear to have had no idea of the advantages derivable from large water-wheels, but contented themselves with additional wheels to meet the demand of additional work. On these occasions every pair of millstones and every pair of fulling stocks had their separate water-wheels, and these were multiplied according to the demands or necessities of the trade. Fig. 247 represents a plan of the wheels,

and the way in which they were arranged, in order to give motion, as was then the fashion, to three pairs of millstones, with a dressing machine and sieves, as the case might require.

Fig. 247.



Most of the mills in this country and in other parts of Europe were of this description up to the middle of the last century; and it was during the days of Smeaton that mills began to assume a better system of classification, and that concentration of machinery and power, which ultimately led to the high state of perfection in which we now find them in this country.

Immediately succeeding Smeaton came the late John Rennie, who built the Albion steam mills, and effected a new system of concentration, totally different to that in use, for corn mills driven by water. The steam engine was, therefore, the first innovator and improver of concentrated power; and Mr. Rennie availed himself of its introduction to effect a new arrangement of the machinery in mills, tending to meet the requirements of a new power concentrated on one point, and diverging in

different directions to reach the various machines of the manufactory. This was an important step gained in the classification of the machinery. It caused a change in the construction of water-wheels by increasing their diameter and width, and by making one wheel do the work of two or three on the old plan, the water-wheel being brought to bear upon the machinery in the mill, on the same principle as that of the steam engine. For many years the old plan still lingered in the minds of the millwrights of the last century, and it was not until the year 1824 that an improved system of applying water power to mills was effectively introduced. This was accomplished at the Catrine Cotton Works in Ayrshire, at the above date. From twenty to thirty years previous to that time these works were driven by four wheels at different parts of the building, with a divided fall of 48 feet, one-half the fall being appropriated to one of the mills and the other to another upon the lower level.

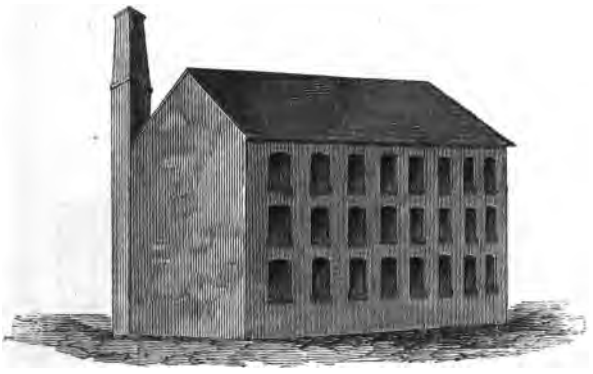
In the new wheels, a description of which is given at page 129, Part I. second edition, the two falls were united, and the whole power concentrated in a separate house, equidistant between the two mills, and a line of strong shafts projected at right angles from the wheels and conveyed the power to the machinery in each. From this system of united force great advantages were derived, both in water and steam, which ultimately led to the arrangements now in use, of having both water-wheels and steam engine erected separate from the mill, thus rendering the establishment free from damp and heat. Water-wheels are now upon a very different system than heretofore, and instead of being sunk in deep trenches in the very centre of the mill, obstructing the different processes of manufacture, and where it is next to impossible to get near them for repairs, they are now erected in a commodious house with broad platforms and galleries, six feet wide, and from which every part of the wheel can be reached.

The concentration of motive power bearing directly from a single point upon mill machinery, led to the introduction of long lines of shafting to reach such machinery at the extreme end of the different flats of the mill, and these, again, as already explained, suggested other improvements in the buildings,

particularly in cotton mills, where they are not unfrequently extended to a length of from 300 to 350 feet.

It is in the recollection of persons still living, when the operations of carding, spinning, and weaving of cotton, flax, and wool, were chiefly carried on in the farm-house and the cottages of the labouring poor, and it is not more than fifty years since the power-loom was introduced, and became the precursor of future changes which ultimately destroyed almost every vestige of our domestic manufacture. It is not for me to offer an opinion on the effects of these changes on the whole of our industrial population; suffice it to observe, that it has altered the domestic habits of the people, and concentrated within large and substantial buildings great numbers of people em-

Fig. 248.



ployed in the different processes of manufacture; and those who were formerly distributed over a large surface of country are now employed under the roofs of weaving sheds and mills. As late as 1784, there were no factories, properly so to speak, but the improvements in cotton machinery introduced by Arkwright and Crompton, suggested enlarged space in the shape of separate buildings; and the large profits arising from the cotton manufacture at that time, enabled the proprietors to build mills, some of them considered of colossal dimensions. At first, these mills were square brick buildings, without any pretensions to architectural form, as shown at fig. 248. This description of building with bare walls was for many years the distinguishing feature of a cotton mill, and for a long period they

continued to be of the same form and character throughout all parts of the country. About the year 1827, I gave designs for a new mill of a different class, and persuaded the proprietor to allow some deviation from the monotonous forms then in general use. This alteration had no pretension to architectural design; it consisted chiefly in forming the corners of the building into pilasters, and a slight cornice round the building, as shown in fig. 249. This simple change of form gave a new impetus to the building of factories. It was speedily copied in all directions with exceedingly slight modifications, but always with effect, as it generally improved the appearance of the buildings, and produced in the minds of the mill owners and the public a higher standard of taste.

Fig. 249.

These attempts at improvement led to the employment of architects, and we have now, as may be seen from the annexed view of the façade of Saltaire, the factory buildings in this country vieing with our institutions and public buildings as works of art, both in the power and harmony of their parts and the *tout ensemble* of their appearance.

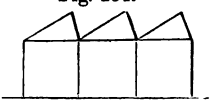
The style of architecture (fig. 250) is not confined to mills of such large dimensions as those of Saltaire, but other forms, according to the taste of the builder, are generally adopted in most mills, greatly to the benefit of the owner, and advantageous in other respects as regards appearance and progressive improvements in the useful arts.

Irrespective of the external appearance, the results of improvements in mill architecture were manifest in the desire which they induced to elaborate with greater certainty and effect the art of design; to accustom the mind to objects of interest which embodied lines of harmonious proportion, and united in these constructions the taste of the architect and the stability of the engineer. To these may be added the improvements that were introduced in the general arrangements of the buildings, their adaptation for the reception of the different kinds of machinery; security from fire and other re-

Fig. 250.

quisites for carrying on a large and successful process of manufacture. Contemporaneous with the architectural improvements in mills, the shed principle lighted from the roof, or the "saw-tooth" system, came into operation. It was chiefly adapted for power-weaving, and contained many advantages in having the machines on the ground floor, accompanied with a slight degree of moisture, which was considered beneficial to the processes carried on.*

Fig. 251.



* This description of building is coming more generally into use for cotton spinning and weaving sheds. See Plate XV. page 179.

Since the introduction of the shed principle as a convenient building for the reception of cotton machinery, it has been generally adopted for workshops, and various other descriptions of manufactures. The workshops at Woolwich and the Enfield Lock Rifle Factory are upon this principle, which have great advantages where the different processes of manufacture are continuous from one department to another, and where the whole can be carried on by rail or tramway, on the ground floor. It is difficult to estimate the advantages of this description of building for manufacturing purposes; they are, however, considerable, and, where land can be had moderately cheap, it is found superior in many respects, particularly as regards light, to buildings composed of three, four, or more stories.*

Another description of building, composed entirely of iron, has been introduced for mill purposes, namely, a combination of cast and wrought iron, as exhibited in a small corn mill, constructed by Messrs. W. Fairbairn, Sons, and Co., Millwall, London, from my own designs, in the year 1841. This building was, to the best of my belief, the first iron house constructed in this country, and was from its unique character one of the most successful constructions of its kind. It was formed of hollow cast-iron pilasters composing the standards and framework of the building, which gave it an architectural appearance, and added considerably to its durability and strength. The spaces between the pilasters were filled up with cast-iron plates to the height of the first floor, and the two remaining stories were formed of wrought-iron plates, riveted to the flanges of the pilasters, as shown in figs. 252, 253, 254, and 255, pages 119, 120, 121, and 122. The whole of the vertical sides and ends were covered with a corrugated iron roof, and the floors were supported by iron beams and columns in the usual manner. This building when completed was exhibited at the works, Millwall, and from that time to the present a large trade in the construction of iron houses, churches, warehouses, &c., has been carried on between this country and the Colonies, India, and America.

* For further detail, *vide* Mr. Fairbairn's work 'On the Application of Iron to Building Purposes.'

CHAPTER II.

ON CORN MILLS.

In the first part of this work was sketched a very brief notice of the antiquity of corn mills, and the state in which grinding went on from generation to generation, until it came down with comparatively little improvement to the present time. During the Jewish period, Moses speaks of the nether and upper mill-stones, and for a succession of ages in Egypt, Greece, and Rome, the quern and some other description of mills, driven by horses or by bullocks, appear to have been in use without change or improvement of any kind. The same may be said of the Middle Ages, which were anything but fruitful of improvement or mechanical invention; and, until the close of the last century, little or no progress was made in the process of grinding, or the development of those principles by which the whole operation is reduced to a system. Corn mills, like every other description of milling, have of late years undergone great changes, and the introduction of steam has given certainty and effect to the mill operations of every description of manufacture, that was inconceivable at a previous epoch. The fact of having motive power at command in every district of the country, mills being no longer dependent upon the state of the wind or the supply of water, has now as nearly as possible supplanted the old wind and water contrivances, and transferred the operation of grinding, with all its necessary improvements, into the very heart of towns. From this certainty of action we derive most of the changes and improvements that are now visible in corn mills, and in every other description of manufacture throughout the country; we have therefore now to show in what these improvements consist, and

how they may be maintained upon sounder principles than those known to our forefathers.

The corn mills chosen for illustration are, one of three pairs of stones erected at Constantinople for the Seraskier Halil Pasha. in 1842, and the other of thirty pairs of stones for a Russian company at Taganrog, on the borders of the Black Sea. The first was built under conditions that the building should be entirely of iron, that it might not be burnt to the ground by the fires which so frequently occur in the Turkish capital. The other was intended for the purpose of grinding the large supplies of wheat which are grown on the steppes of Southern Russia for the European markets, and also for the supply of bread and biscuits for the Russian navy.

It is now upwards of forty years since the new system of corn mills, having the millstones in a continuous line, was first adopted. For many years it was called in question, and it met with a determined opposition from the old millers and millwrights, who stoutly maintained that the bevel-wheel principle was decidedly inferior to the old plan of stones ranged round a large spur wheel. Time, however, showed the advantages of the new plan, as it not only proved that the bevel wheels worked as well as the spur, but it gave greatly increased facilities for the operations of the mill in the different processes of cleansing, grinding, dressing, sacking, &c., of the flour, as it came from the machine ready for the baker.

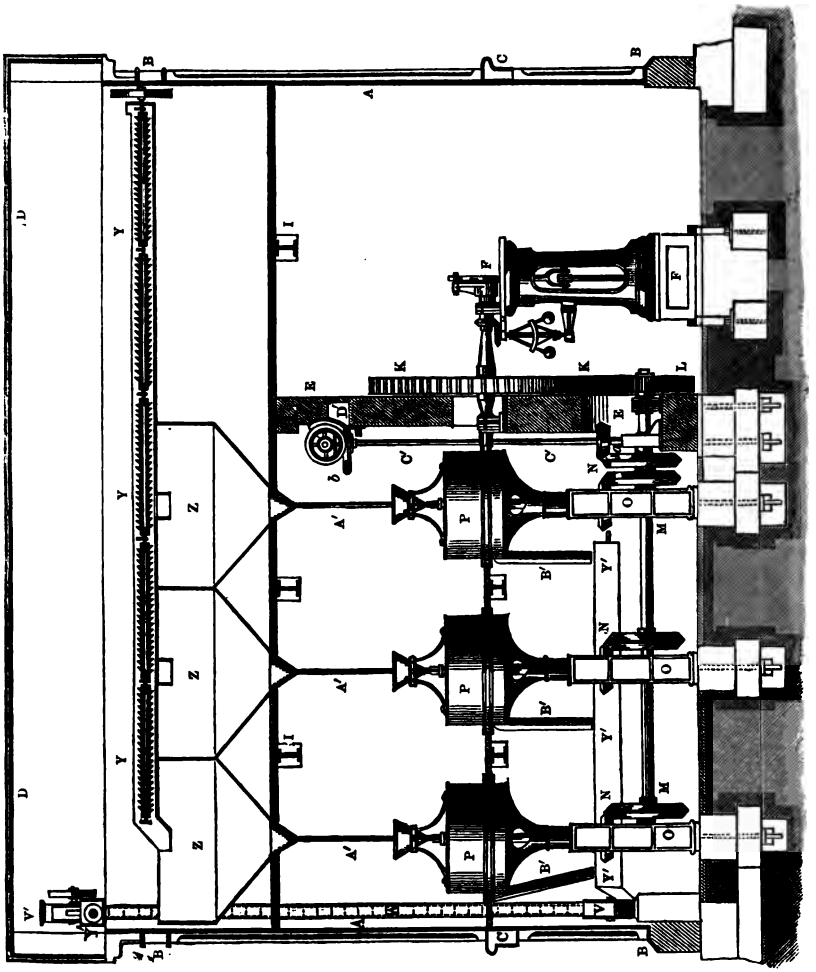
A description of this mill, and of the Old Union Mills, Birmingham, was published some years since by Messrs. Blackie and Son, in their work, entitled 'The Engineers' and Mechanics' Assistant,' and, as that work contains an accurate description of this system of mills, I have extracted from it large quotations, accompanied with improvements, which have since been introduced.

Fig. 252 is a sectional elevation of the mill, the line of section being taken in a longitudinal direction, and exhibiting the position of the stones, the engine, and driving gearing, and of such portions of the subordinate apparatus as are visible on the side of the mill which is exposed to view.

It also exhibits the millstones P P P, sections of the ele-

vator v v′, screw creepers y′y′, and the wheat bins or hoppers z z z.

Fig. 252.



In these will be seen the driving gear K K, first motion wheels K L N N, and vertical shaft c′c′, by which motion is transmitted to the machinery in the floors above.

Fig. 253 is a plan of the bottom floor, showing the engine F and boilers G G, corresponding to the above, and taken on a horizontal line passing through the lower story of the mill.

Fig. 253.

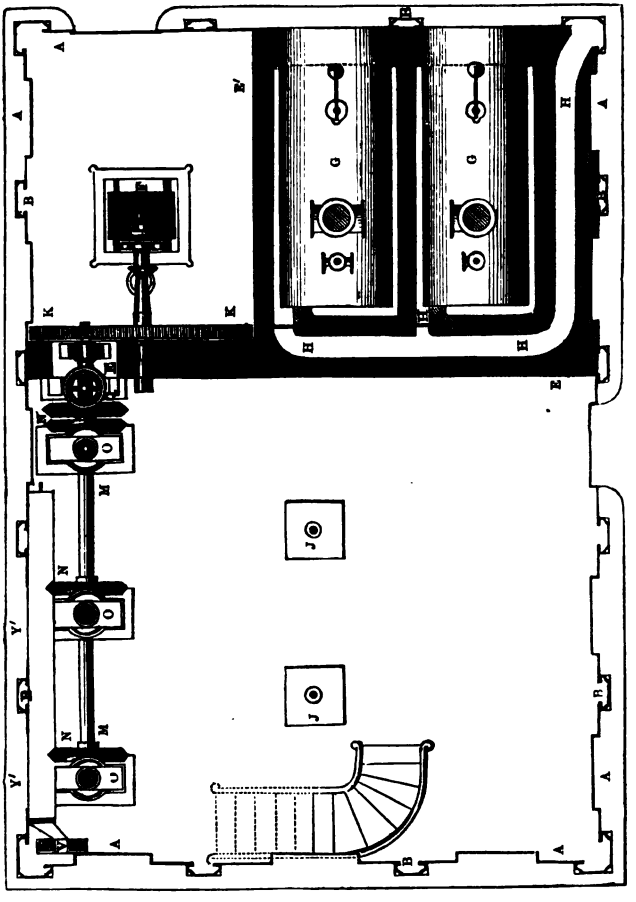


Fig. 254 is a transverse section of the entire mill, in which are shown the garners for undressed and dressed wheat Q Q, the mechanism by which it is cleaned and conveyed from the former into the latter, as described in the text, page 124, and in the references at pages 125 and 126; the sack teagle, &c., as shown at H′D, &c.

Fig. 254.

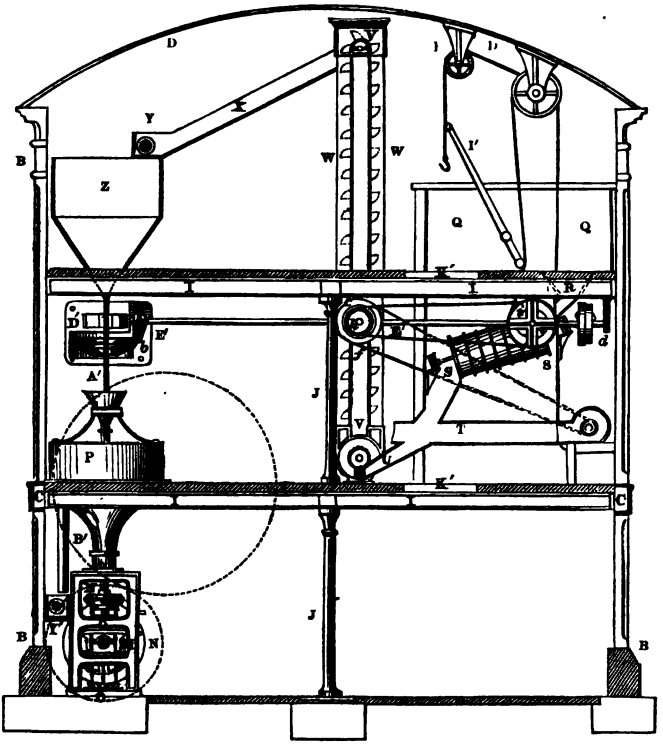
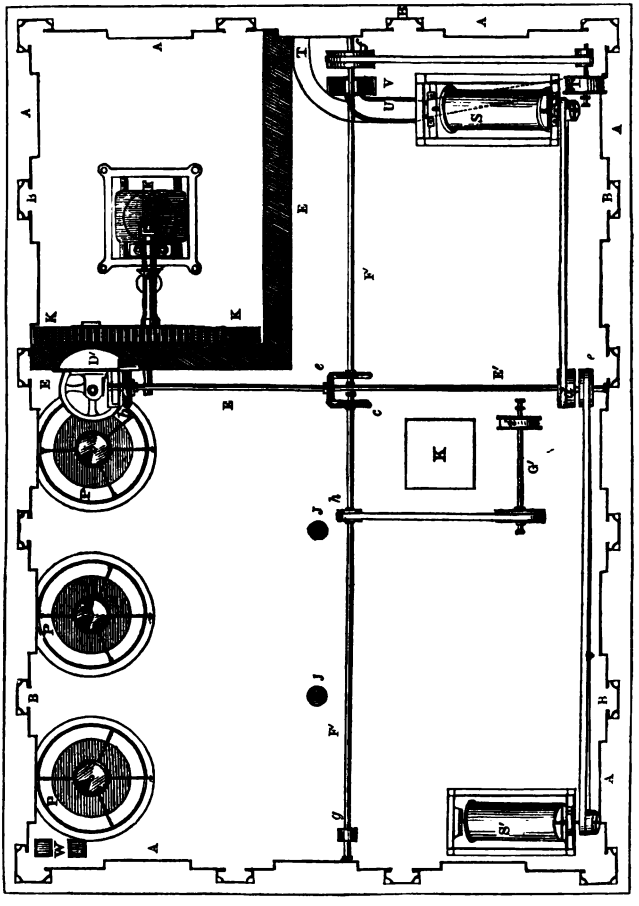


Fig. 255 is a plan of the first floor, corresponding with the plan, fig. 253, the line of section being taken through the first story of the mill.

The house in which this mill is contained consists of an assemblage of plates of sheet iron A, A, A, of a suitable thickness, consolidated and bound together by the square cast-iron columns, or pilasters B, B, B, and by the strong cast-iron girders C, C, C, situated at such a height as to oppose and neutralise the strain of the principal working parts. It is surmounted by an arched roof D, D, formed of plates of corrugated sheet-iron. A wall of masonry E, E is erected in the interior, for the purpose of affording a foundation for the bearings of the heavier gearing of the mill. The motive power is supplied by a high-pressure steam-engine F, of 12 horse

power, the distinguishing feature of which consists in its principal working parts being wholly enclosed within a large cast-iron column. By this arrangement great firmness and stability

Fig. 255.



are imparted to the engine, while the space which it occupies is reduced to the smallest possible dimensions. The boilers G, G are situated in an adjoining part of the house, and their flues H,H are formed, in the usual manner, of brickwork, abutting

on the one hand against the wall E, and on the other against the side of the house itself. Thus the engine and boilers occupy nearly the entire half of the lower story of the mill. The whole erection is strengthened and bound together by the cast-iron beams I, I, I, which pass transversely through the interior of the house, and are supported in the middle of their length by the columns J, J. On these beams, also, the flooring of the upper and lower flat is disposed.

The fly-wheel K, K of the steam engine is of that kind denominated spur fly-wheels, from the circumstance of their being formed with teeth, on the exterior of the rim, and thus serving at once to regulate the velocity, and to transmit the power of the steam engine to which they are attached. The spur fly-wheel K, K, the diameter of which is 9 feet $3\frac{3}{4}$ inches, gears with the pinion L, fig. 252, of 4 feet $10\frac{3}{4}$ inches diameter; consequently, the velocity of the crank shaft is nearly doubled upon the horizontal shaft M, M, to which the latter is fixed, and which by means of the bevel wheels and pinions N, N, N gives motion to the stones contained within the millstone cases P, P, P. The shaft M, M has a bearing upon the wall E, close to the back of the pinion L, and one in each of the standards O, O, O (figs. 252 and 253), to which the mechanism necessary for impelling and regulating the action of the stones is attached.

Considerable difference of opinion exists amongst the millwrights of the present day regarding the comparative advantages of spur and bevel gearing as employed for driving grinding machinery. Into this question our limits do not admit of our entering; in our examples we have chosen the latter method, as being that most generally practised. We may, however, be permitted to enumerate a few of the more obvious advantages attending the present system.

1st. It admits of the stones, whatever may be the number employed, being ranged in a straight line instead of in a circle, thereby economising space, and tending to a more convenient and economical disposition of the garners and apparatus by which they are fed.

2nd. It dispenses with the cumbrous and expensive framework necessary for binding together the parts of the system of spur gearing.

3rd. It admits of the employment of wheel-work of a finer pitch, and consequently of a more smooth and equable action, than could be used in the other case. And,

4th. The use of the bevel gearing increases the facility of disengaging at pleasure any pair of stones which may require examination or repair.

We shall now proceed to describe the mechanism of the various processes by which the grain is treated, both previously and subsequently to the process of grinding; and, to avoid repetitions, we shall notice these processes in the order in which they occur.

The corn to be ground is deposited in the upper floor of the mill in the large garner Q Q, fig. 254, from which it is conducted through the spout R into the screening machine S, S, where it is cleansed of the dust and other extraneous matter which is found more or less combined with it. The corn enters at its upper extremity, and having been thoroughly agitated in its passage through the interior of the machine, and thereby divested of the greater portion of the refuse with which it was mixed, falls into a spout U, at its lower end, which conducts it to the elevator V; being subjected in its passage through this spout to the action of a blast from the fan T, by which the remaining portion of the sand and dust that escapes with the grain is carried off by a passage leading to the exterior of the house. The grain, after being thus cleansed, is caught by the elevator V, and raised nearly to the summit of the mill, where it is delivered, through an inclined spout X, into the creeper-box Y Y, by which it is distributed into the feeding garners Z, Z, Z (fig. 252).

The corn which is supplied to the garners Z, Z, Z falls through the feeding pipes or spouts A′, A′, A′ (fig. 252) into the hoppers, by which the grinding apparatus is surmounted. After being reduced into flour, it falls through the pipes B′, B′, B′ into the creeper-box Y′, Y′, by which it is transferred to the elevator V. By this elevator it is again raised to the summit of the house, and carried by means of the creeper Y′ to the dressing machine S′ (fig. 255), after passing which the different products are stored up in sacks, or otherwise disposed of, as may be most convenient. The machines and mechanism connected therewith will subsequently be very fully described, and need not here be further alluded to.

The gearing by which the subordinate machinery of the mill is driven, consists, first, of an upright shaft C, C′ (fig. 252) set in motion by a pair of bevel wheels *a*, from the main horizontal shaft M, M. This shaft has its lower bearing in an arched standard embracing the shaft M, and at its upper extremity it is supported by a plummer-block bolted to a double bracket D′ embedded in the wall E. Its motion is here transferred by means of another pair of bevel wheels *b* to the horizontal shaft E′, E′ (fig. 255), passing transversely across the mill. On this shaft are fixed the pulleys *d* and *e*, which drive the screening and dressing machines respectively, and a set of small bevel wheels *c*, *c*, serve to transmit the motion to the longitudinal shafts F′, F′, by which the elevators, creepers, &c., are propelled; as also the short shaft G′, by which the sack teagle is driven.

We subjoin a list of the various wheels, pinions, and pulleys employed in this mill, and the velocities imparted by them to the machines driven by them respectively.

STEAM ENGINE F, 12 HORSE-POWER, MAKES FORTY REVOLUTIONS OF CRANK-SHAFT PER MINUTE.

Description of Gearing	Driver		Driven		Result Revolutions per Minute
	Diameter	Revolutions	Diameter		
	ft. in.		ft. in.		
Spur pair K, L	9 3¾	40	4 10¾		76 on horizontal shaft M.
Bevel pairs N, N, N	3 6	76	1 10		140 on the stones.
Bevel pair *a*	3 6	76	1 10		140 on upright shaft C′.
Bevel pair *b*	3 0	140	1 9		242 on transverse shaft E′.
Bevel pair *c*, *c*	1 1½	242	1 11½		140 on longitudinal shafts F′ F′.
Pulley *d*	1 6	242	1 0		363 on screening machines.
Pulley *e*	1 6	242	1 0		363 on dressing machine S′.
Pulley *f*	2 0	140	0 6		560 on fan T.
Pulley *g*	0 8	140	2 0		46·6 on elevators & creepers.
Pulley *h*	1 0	140	2 0		70 on intermediate shaft G′.
Pulley *i*	1 6	70	2 0		47 on sack teagle H′.

REFERENCES.

A, A, A, the sheet-iron sides of the house in which the mill is erected.

B, B, B, columns for supporting and strengthening the structure.

C, C, horizontal beams at the level of the first floor.

D, D, the roof formed of corrugated iron.

E, E, a wall of masonry, affording a foundation for the bearings of the driving gearing, &c.

F, the steam engine by which the mill is driven.

G, G, the boilers.

H, H, the flues and seat of the boilers.

I, I, I, transverse cast-iron beams for supporting the floors, &c.

J, J, columns for supporting these beams.

K, K, the spur fly-wheel of the engine.

L, pinion working into the above.

M, M, the main horizontal shaft.

N, N, N, bevel mortice wheels and pinions by which the millstone spindles are driven.

O, O, O, the standards of the grinding machinery.

P, P, P, the millstone cases.

Q, Q, the large garner for uncleaned wheat.

R, spout leading from the garner, Q, to

S, the screening machine.

S′, the dressing machine.

T, a fan attached to the wheat screen.

U, spout leading from the wheat screen to

V, W, the first elevator.

X, passage conducting the grain from the first elevator to

Y, Y, Y, the creeper, by which it is distributed into

Z, Z, Z, the garners for feeding the stones.

A′, A′, A′, the feeding pipes.

B′, B′, B′, pipes by which the pipes are delivered into

Y′, Y′, the second creeper box, conducting it to

V′, W, the second elevator.

a, bevel wheel and pinion giving motion to

C′, C′, the vertical shafts of the mill.

D′, a cast-iron support for the bearings of the vertical and transverse horizontal shafts.

b, bevel wheel and pinion giving motion to

E′, E′, the transverse horizontal shaft.

c, *c*, a set of small bevel gearing, giving motion to

F′, F′, the longitudinal horizontal shaft.

d, *e*, *f*, *g*, *h*, *i*, pulleys for giving motion to the various subordinate machinery of the mill.

G′, intermediate shaft, conveying motion to

H′, H′, the sack teagle.

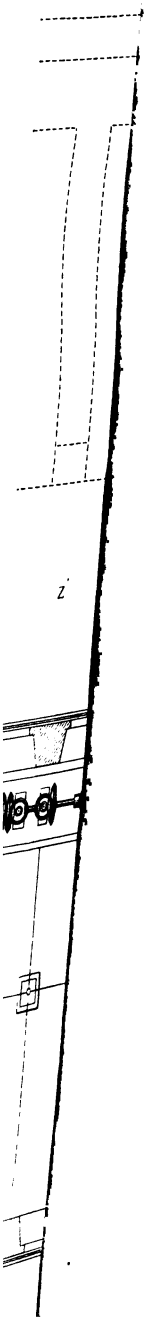
I′, a lever for stopping and starting the sack teagle.

K′, K′, hatchways by which the sacks are admitted or withdrawn.

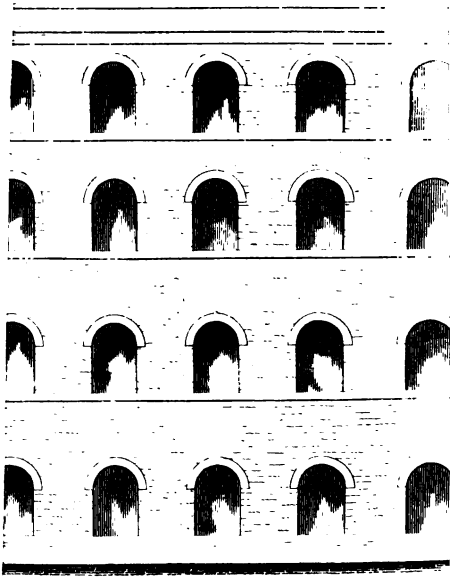
z'

z'

STONE



CORN MILL OF 36 PA



he next example of a corn mill on a large scale is the tly constructed mills of Taganrog, on the north shore of Black Sea. It consists of 36 pair of stones and all the inery requisite for grinding 180 to 200 bushels of clean wheat per hour. It was built for the purpose of a general e, and a bakery for bread and biscuit for the Russian navy, the machinery for this latter department has not been ed, and the operations have hitherto been confined to ding alone.

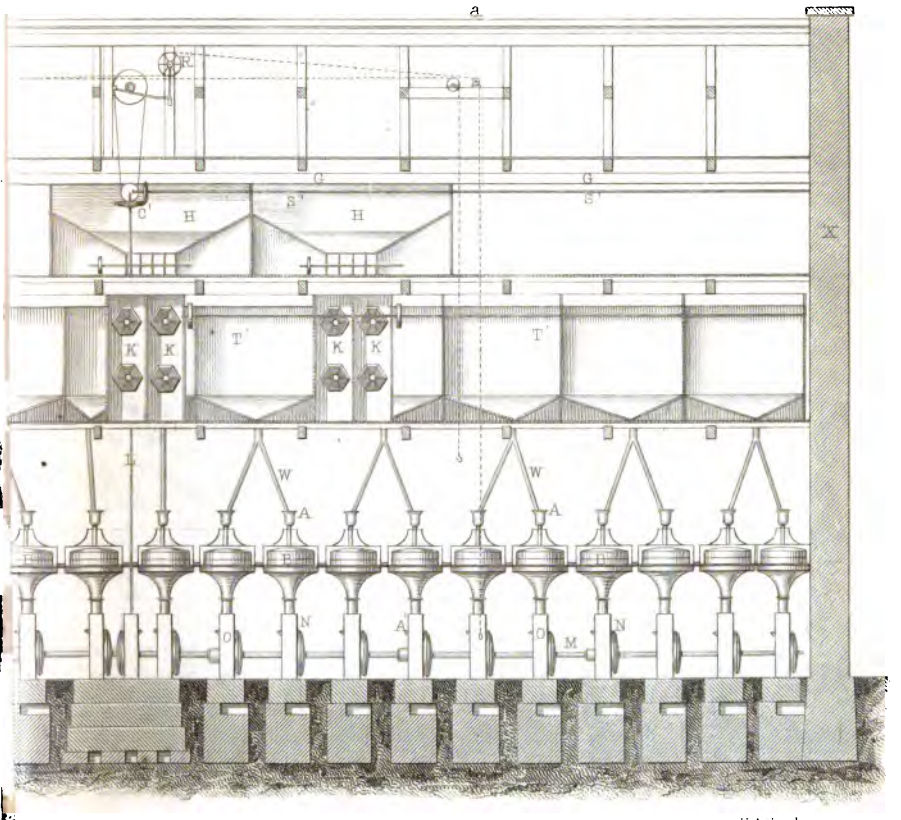
late XI. is a front elevation of the mill, and Plate XII. a plan wing the position of the engines. The engines work in con- with the cranks at right angles; and the boilers, which are under the surface of the ground, immediately adjoining engine-house, are fired from the space z'. The chimney *n* laced in a line with the centre of the engine-house and the . Plate XIII. is a longitudinal section which exhibits the tion of the machinery, millwork, millstones, &c.; and te XIV. exhibits a transverse section, taken from a line wn through the centre of the engine-house and the fly-wheel. The motive power is supplied by two 100 horses power engines ited in the fly-wheel *l* (Plate XIV.), 24 feet 5 inches diameter. is on the new principle of a first motion, with 230 teeth, inches pitch, and 14 inches broad on the tooth, and makes ·7 revolutions per minute. The engines have a stroke of feet, and the steam is supplied by six boilers, each 30 feet inches long and 7 feet diameter. The chimney is octagonal, nd placed 40 feet from the engine-house, with underground ues and an outlet of 5 feet wide at the top. The walls are feet 6 inches thick at the bottom, and taper to 1 foot 3 inches t a height of 140 feet. The engines are situated behind in the entre of the mill, and the power is given off at both sides of the pinion, which gears into the fly-wheel at a velocity of 87·7 revolutions per minute. For a distance of 14 feet on each side the main shafts are 8¼ inches diameter, for a farther distance they are 7¼ inches diameter, and from this point they taper respectively to 6½ and 6 inches diameter on both sides. The distance between the centres of each pair of stones is 5 feet 6 inches, and they are arranged in a straight line running parallel to the walls through the entire length of the building.

The bevel mortice wheels on the main horizontal shaft are 3 feet $4\frac{3}{4}$ inches diameter, and the bevel wheels N, N, N on the millstone spindles are 2 feet $1\frac{1}{2}$ inches, and make 140 revolutions per minute. The elevators for meal D D rise perpendicularly at either end of the building to the attic story, and the shafts L L for driving the subordinate machinery in the different flats, rises to the fifth story, giving off its power to the different machines on its course by bevel wheels. The third story of the mill contains the dressing and bolting machines F, F and K, K, also the wheat bins (Plate XIII.) V, V, V for the supply of the corn to the millstones. These wheat-bins are about 11 feet square and 12 feet high, and are supplied by the elevator and creeper Q and U, so that manual labour is entirely dispensed with. The fourth story contains the screening machines T, T, T, and the garners for the bolting machines H, H, these being also supplied by creepers and elevators. The attic story contains the separators S S and the hoists R′, R′, &c. &c.

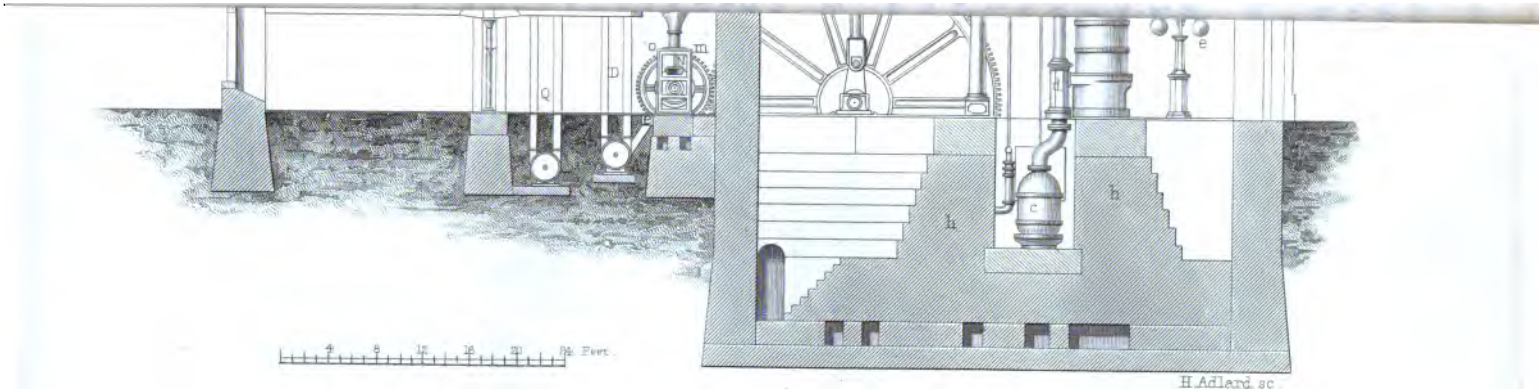
The wheat enters the mill from the granary at *n′*, and by the elevator Q is carried to the creeper R, by which it is conducted to the separators S, S. Having passed through the separators, and the earthy particles, dust and small grain, having been abstracted, it enters the wheat screens T, T; here it is subjected to a thorough brushing, and the dust falls through the wire gauze of which the screen is composed. On its way to the creeper U it is subjected to the action of fans J, J, J, which blow out any remaining dust; it is then conveyed by the creepers to the wheat bins V, V, V, where it is stored, and supplies itself in sufficient quantity through the feed pipes W, W, W into the hoppers A, A, A, and from thence descends to the millstones B, B, B. After having been ground, it falls through to the meal creepers, by which it is conveyed to the elevators D, D, and from thence, by another creeper, to the dressing machines and the garners for the bolting machines H, H, H. There the meal undergoes the last process, where the flour is separated from the bran and is ready to be stored in sacks for the market.*

* Some few years ago two conical mills were introduced: the one by Mr. Schiele of Oldham, which consisted of a conoid of stone of peculiar form, placed with the base upwards, which merely fitted into a block of stone hollowed out to receive it,

ELEVATION.



H Adlard sc



London Longman & Co.

This large establishment was originally intended not only for the supply of biscuit for the Russian Navy, but for export in the shape of flour in place of wheat. The Crimean war, the destruction of Sebastopol, and the subsequent treaty of peace, whereby it was agreed that no vessels of war should be retained on the Black Sea excepting those for the protection of commerce, have changed the objects originally contemplated by the erection of these mills, and have caused the Company to abandon the Baking department, and confine their operations to the simple process of grinding, dressing, &c.

It is for these reasons that we are necessitated to confine our description to the various processes through which the corn passes; and as the construction of the various machines and the mechanical appliances for the saving of manual labour are described in detail at the end of this section, further reference to them here is rendered unnecessary.

In order to make the description as complete as possible, we append a list of wheels and speeds, including the Table of References, which will also be found serviceable.

and in which it revolved. The form given to these stones was a curve termed the equitangential tractory, which by revolving on its axis generates the conoid.

The other conical flour mill was the invention of Mr. Westrup. The points of peculiarity in this mill were, that there were two pairs of stones to each mill. Between the two pairs of stones a cylindrical screen of about 2 feet 6 inches high was fixed. The lower instead of the upper stones revolved, and brushes were attached to the spindle, in the space between the two sets of stones, by which the finest flour is brushed through the vertical cylinder. The bottom stones are convex, and make about 250 revolutions per minute; the upper ones are concave, and about 2 feet 6 inches diameter. When the eye-hole is cut out, it leaves some 9 inches of grinding surface, and in that width the bevel of the cone is 4 inches. Cold air is introduced between the stones by means of a fan, which blows out the meal from between them. The stones are fed by means of a hopper placed on one side, with a feed pipe in the top of it, and an upright spindle carrying a dish, which, revolving quickly, evenly distributes the corn.

LIST OF WHEELS AND SPEEDS.

Description of Gearing	Marks	Diameter of Wheels and Pulleys		Number of Revolutions	Geared into Wheels of Diameter		Result—Revolutions per Minute		
		ft.	in.		ft.	in.			
Fly wheel	———	24	5	21·7	6	0½	87·7 revolutions of main driving shaft.		
Bevel wheels	A′ A′, &c.	3	4¾	87·7	2	1½	140	„	millstones and upright shafts.
„	B′	3	0	140	1	9	242	„	cross shaft for driving dressing machines.
„	C′ C′ C′, &c.	2	6	140	2	1½	164·3	„	shafts.
„	D′	2	6	164·3	2	1½	192	„	cross shaft for driving wheat screens, &c.
„	E′	1	9	192	2	5	140	„	cross shaft for driving fans and creepers.
Pulleys	F′ F′	2	7½	242	1	3	500	„	dressing machines.
„	G′ G′ G′	2	6	192	1	3	380	„	wheat screens.
„	H′ H′ H′	2	6	140	0	7	600	„	fan for screens.
„	I′ I′ I′	0	9	140	1	6	70	„	creepers under wheat screens.
„	J′	0	10	192	2	5½	65	„	counter shaft for driving separator.
„	K′ K′ K′	0	8	52	2	3½	20	„	separators.
„	L′	1	0	164·3	2	0	82	„	creepers over the wheat separators.
„	M′	1	2	164·3	1	8	114	„	cross shaft for large creeper over wheat garners.
Spur wheels	N′	0	8⅝	114	2	11½	27	„	large creeper over wheat garners.
Pulleys	O′ O′, &c.	1	0	164·3	2	2¼	75	„	small creeper over wheat garners.
„	O O	1	0	164·3	2	2¼	75	„	small creeper over bolting machines, garners, and cooling room.
„	P′ P′	1	9	87·7	2	2¼	72	„	small creeper for meal in ground floor.
„	Q′ Q′ Q′	0	8	164·3	2	5½	45	„	elevators for wheat and meal.
„	R′ R′, &c.	1	2	164·3	3	0	64	„	chain barrels 10 inches diameter for hoists.
„	S′ S′	1	2½	164·3	3	0	66	„	cross shafts for bolting machines.
„	T′ T′	1	6	66	1	6	66	„	second cross shaft on bolting machines.
Bevel wheels	U′ U′	0	7	66	1	9	22	„	bolting machines.
Pulleys	V′ V′	0	6	66	1	6	22	„	scraper shaft.
„	W′ W′	1	0	22	1	0	22	„	scrapers.

REFERENCES TO PLATES XII. XIII. AND XIV.

X, X, the walls of the mill.

Y, Y, Y, columns for strengthening the building and supporting the floors.

a, *a*, *a*, the roof of the building.

f, the steam engine by which the mill is driven.

b, the cylinder.

c, the condenser.

d, *d*, the feed pipes.

e, the governors.

g, the main beam.

h, *h*, the foundations.

l, the spur fly wheel of the engine.

m, the pinion gearing into the above.

M, M, the main horizontal shaft.

N, N, bevel mortice wheels and pinions by which the millstone spindles are driven.

O, O, the standard frame and inverted cone supporting the millstones.

P, P, the millstone cases.

Q, the elevator for lifting the wheat from the garners to the separator.

R, the creeper to supply the separators.

S, S, S, the separators.

T, T, the wheat screens.

J, J, the fan attached to the wheat screens.

U, U, U, the creeper conveying the grain to

V, V, V, the wheat bins, and through

W, W, W, the feed pipes, to

A, A, A, the hoppers, and to

B, B, B, the millstones.

C, C, C, the creeper for conveying the ground corn to

D, the meal elevator.

E, E, the creeper for conveying the ground corn to the cooling rooms ready to be supplied as required to

F, F, the dressing machines.

G, G, the creeper for conveying the ground corn to

H, H, the garners of the bolting machines.

K, K, the bolting machines.

L, L, the shafts for driving the subordinate machinery.

B′, the bevel wheels giving motion to the cross shaft of the dressing machines.

C′, bevel wheels giving motion to
D′, the cross shaft for screening machines.
A′A′, bevel wheels on upright shaft.
I, the dust chamber for the wheat screens.
n, the chimney.
o, the reservoir for supplying the boiler of the engine.
Z, the store room for flour.
Z′, the space from which the boilers are fired.
E′, cross shaft for driving fans and creepers.
F′, F′, pulleys for driving dressing machines.
G′, G′, G′, pulleys for driving screening machines.
H′, H′, H′, pulleys for driving fans for screens.
I′, pulley for creeper under wheat screen.
J′, counter shaft under separator.
K′, K′, K′, pulleys for separators.
L′, pulley for creepers over wheat screen.
M′, cross shaft for creeper over wheat garners.
N′, spur wheel for large creeper over wheat garners.
O′, pulley for small creeper over wheat garners.
P′, P′, pulleys for meal creeper on ground floor.
Q′, Q′, pulleys for meal elevators.
R′, R′, the chain barrels of the hoists.
S′, S′, cross shafts for bolting machines.
T′, T′, second cross shaft for bolting machines.

During the siege of Sebastopol it was determined, on the urgent recommendation of Assistant-Commissary General Julyan, to effect an arrangement for supplying the troops daily with new bread and fresh flour from the grain of the surrounding country, by providing the means of converting the wheat into flour and baking it upon the spot by a floating mill and bakery. Having been consulted as to the best means of carrying out this proposal, drawings and plans were prepared for the mills and ovens, and two iron screw steamers, subsequently named the Bruiser and the Abundance, were purchased by the Government for adaptation to this purpose, and were fitted with machinery by Messrs. William Fairbairn and Sons, the whole being completed in less than three months.

It is curious to trace the history of the means by which large bodies of men have been supplied with food, and the obligations

assumed by states for provisioning armies in times of war. We learn that, in the early period of Roman history, grain was the only article of food issued to the soldiers, and was ground by means of a hand-mill, which formed a part of every man's equipment; the flour was simply worked into a paste called *puls*, which constituted the principal food. The constitution of modern armies and the peculiar character of modern warfare render the soldier, however, more dependent upon the cares of the administration than was the case with the ancients; and we have seen how prostrate and helpless they are, when deprived of the resources of a well-conducted and far-seeing commissariat. The French, Spanish, and other continental troops can live upon a moderate allowance of vegetable and farinaceous food, and a lump of oil cake will maintain a Russian for a week; but it is widely different with the English, who become disorganised when their rations fail. Under these circumstances it is a matter of essential importance to maintain a system of daily supply; and hence followed the introduction of the floating mill and bakery.

The arrangement of the floating mill is shown in figs. 256, 257, 258, and 259. Fig. 256 is a longitudinal section of the vessel; fig. 257 is a plan of the machinery, with the decks removed and partly in section; and figs. 258 and 259 are transverse sections of the vessel.

The mill machinery is all driven from the propeller shaft A (figs. 256 and 257), which is driven by the engines B; and the whole of the processes are performed without the aid of manual labour. The wheat is stored in the forehold of the vessel, and is raised by an elevator into the screw-creeper C, which conveys it into the corn-dressing machine D, where it is cleaned and winnowed. Thence it is again conveyed by the elevator E and the screw-creeper F into the hoppers G G for feeding the mill-stones H H, by which it is ground. The grain is fed to the stones by the silent feeders I, now in general use in this and foreign countries. After being ground by the mill-stones H, the flour or meal is delivered into the screw-creeper K, which conveys it to the elevator L, by which it is delivered into the flour-dressing machine M; it is here freed from the bran and filled into sacks, having been separated into a fine and coarse quality. This

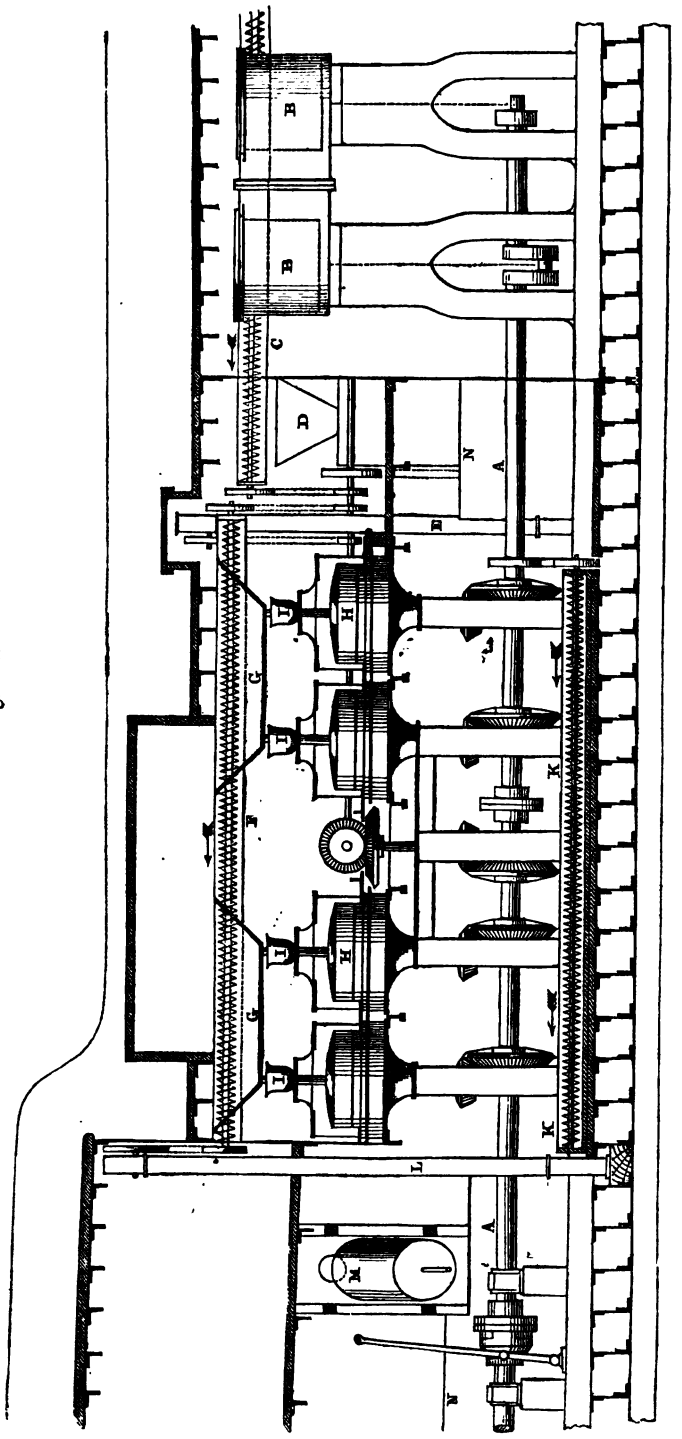


Fig. 256.

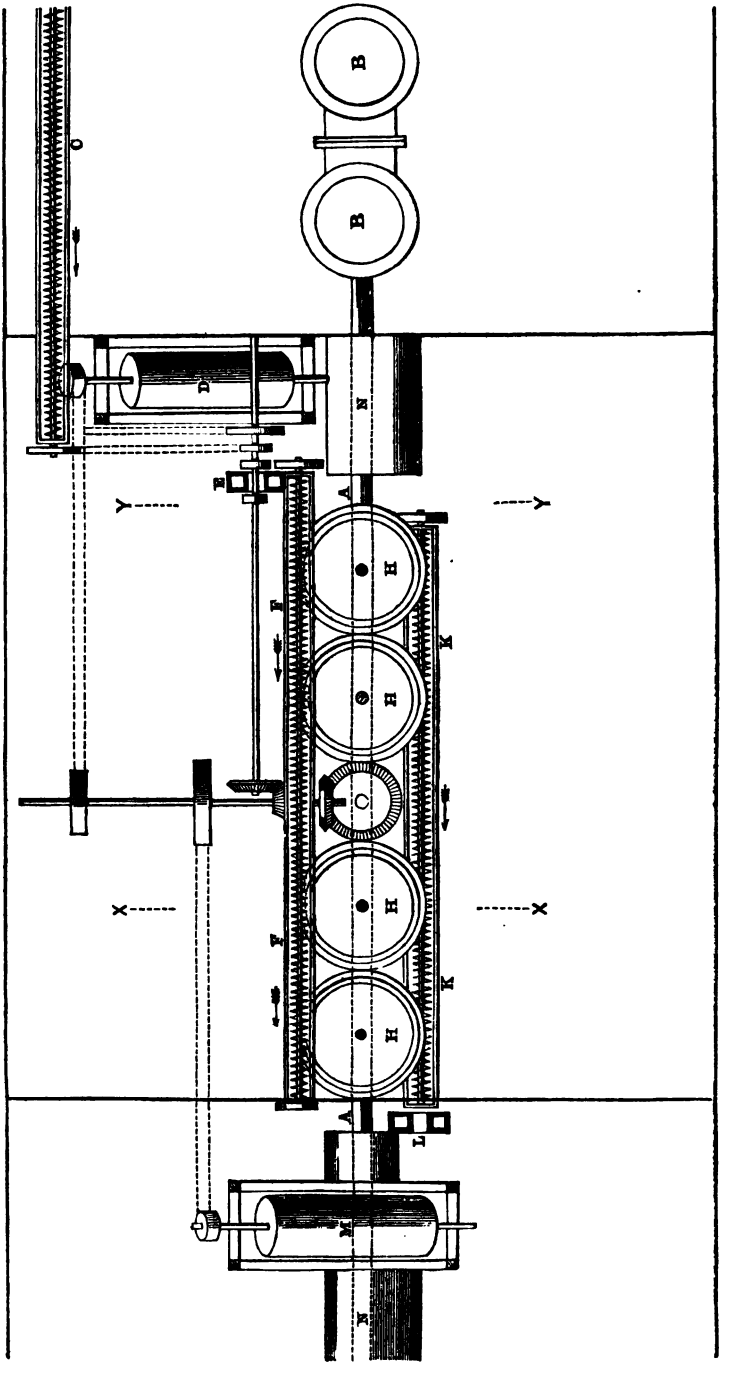


Fig. 257

Fig. 258.

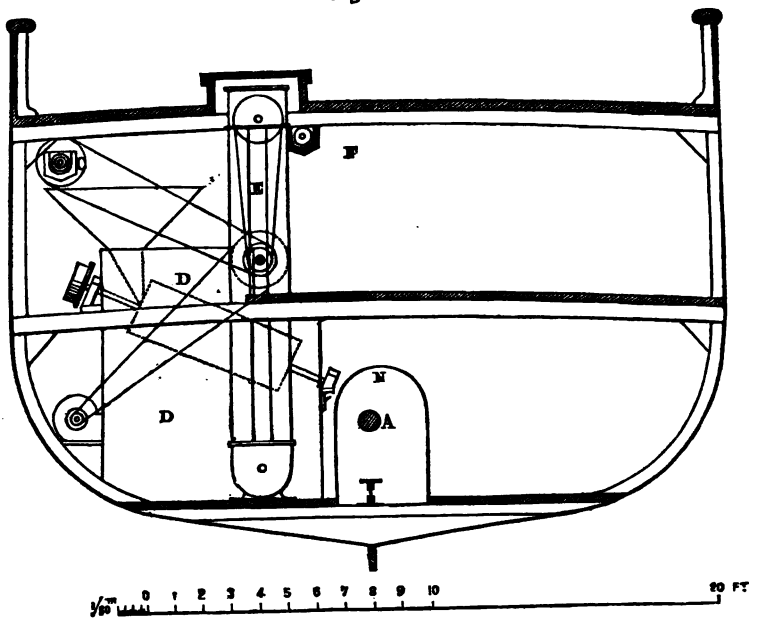
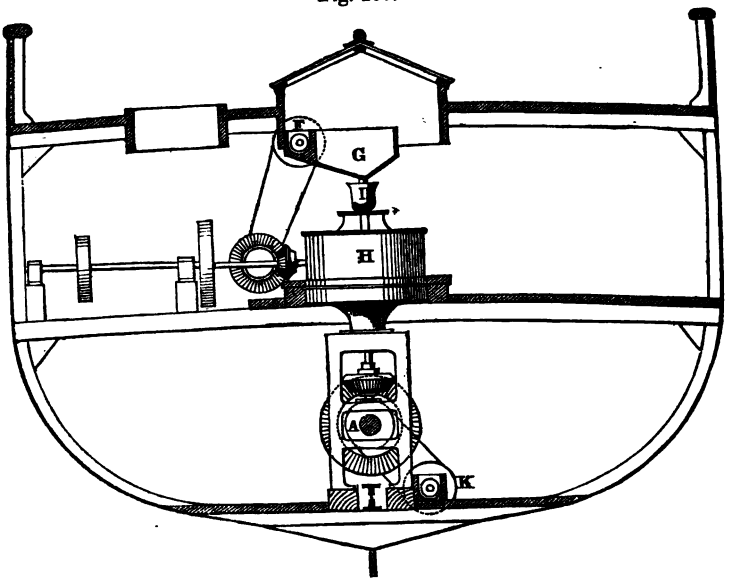


Fig. 259.



completes the whole process. The propeller shaft A is exposed under the mill-stones, but covered by an iron trough N in the other parts of the vessel.

During the time the vessel was in harbour at Balaklava, the daily produce of flour from this mill was about 24,000 lbs., and that from very hard wheat, full of small gravel, and consequently the more difficult to grind. It was originally intended that the mill should be capable of producing 20,000 lbs. of bread per day, but it proved equal to a considerably larger production; and not the least important of its good qualities was, that it never got out of order during the whole period of service in the Black Sea. From the reports made to the Government at home respecting its working, it appears that important advantages were gained by the introduction of this machinery for the use of the troops. There is probably no description of food so essential to the maintenance of health and the recovery of the sick as fresh flour and fresh bread; and the salutary effects produced upon the health of the troops and the number of lives saved in the late war, by the abundant supply of wholesome bread and flour that was poured into the camp during the latter part of the siege, forcibly suggest the necessity of a light portable steam-engine and mill for grinding being constantly attached to the camp, whenever or wherever an army takes the field. This can be done at a very moderate cost, and, in my opinion, no army should attempt to take the field without it. The whole affair would not exceed the weight of a heavy siege gun, such as now accompanies our armies; and there appears no practical difficulty in the way of introducing an engine capable of supplying newly-baked bread, from an oven constructed in the smoke-box of a portable locomotive engine mounted on wheels and prepared to grind at the same time.

The results of the working of the floating corn mill are given in the official reports at 20 tons of flour ground per day of 24 hours when constantly in full work; and 18,000 lbs. of bread in 3 lb. loaves produced daily from the bakery. This rate of work was continued uninterruptedly for many months, and the machinery answered completely the object intended. The total quantity of bread produced in three months from January 1 to March 31, 1856, was 1,284,747 lbs.; and the

expenses of working were 2,017*l.*, or 3*s.* 2*d.* per 100 lbs. of bread made, including the expense of a sea establishment for the vessel, which would not be required where the vessel was stationary. The quantity of flour ground in the same period was 1,331,792 lbs. with 358,172 lbs. of bran, the wheat supplied being 1,776,780 lbs.; the expenses of working were 2,050*l.*, or 2*s.* 4*d.* per 100 lbs. of wheat ground, or 3*s.* 1*d.* per 100 lbs. of flour produced. The total cost of the flour produced was therefore about 25*s.* 3*d.* per 100 lbs., the wheat costing about 18*s.* per 100 lbs., and the value of the bran being deducted at 7*s.* per 100 lbs. or less than 1*d.* per lb.

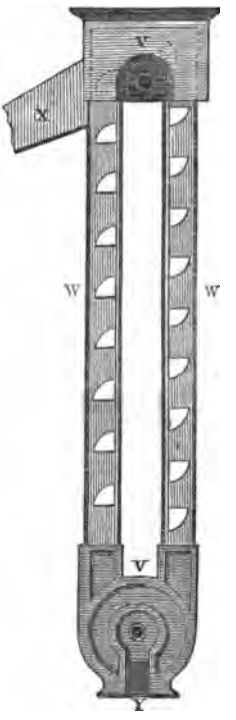
The grinding of wheat was found to be performed quite satisfactorily whilst the vessel was at sea, even in a heavy swell causing an excessive motion, which tried the fitness of the machinery for the work to an unusual degree; the grinding whilst the vessel is performing her voyage being obtained from the same power that propels her. On one occasion, when the vessel was steaming 6½ knots or 7½ miles per hour, 10 sacks of 168 lbs. each or 1,680 lbs. of wheat were ground per hour, and the mill was kept in constant work for 35 hours, the men being divided into watches of 4 hours each; the mill continued working well throughout, and was found to run more regularly than when the screw was disconnected.

The mill machinery of the Bruiser is similar to that ordinarily employed on shore in this country, with such modifications only as were necessary to adapt it to its novel position, and fit it to sustain the constant and varying motion of the vessel at sea. These difficulties were overcome, and the mill was found to answer admirably, grinding, in almost all weathers, at the rate of 20 bushels, or 1,120 lbs. of flour per hour, and that at a time when the vessel was steaming at 7½ knots or 8½ miles per hour, both the mill machinery and the ship being propelled by the same engines, which were constructed by Messrs. Robert Stephenson and Co., of 80 horses' power.

Details of Machinery.

The elevator consists of a long endless chain of small buckets formed of tin plate, and mounted at regular distances upon a leather or canvas band passing over two pulleys inclosed within the cast-iron frames V, V, and the wooden boxes W, W.

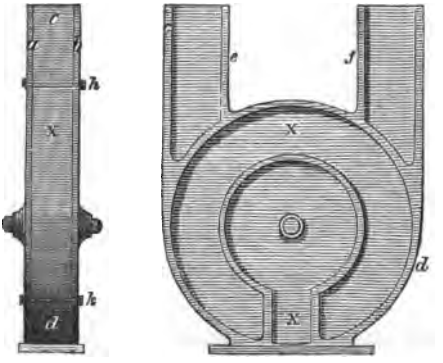
Fig. 260.



The uppermost of these pulleys is driven at a moderatevelocity by a belt, and the buckets passing in succession the opening Y (which is kept constantly supplied with the material to be raised by means of an inclined spout) become each charged with a certain portion, which is carried up one side, and from which it falls through the spout X into the garner or the machine prepared for its reception. From this it will be seen that the buckets, having discharged their contents into the spout X, descend empty on the opposite side, ready to receive or take up their respective load as they pass the feed-spout Y, under the lower pulley.

The lower part of the elevator is shown in fig. 261. It consists of two cast-iron

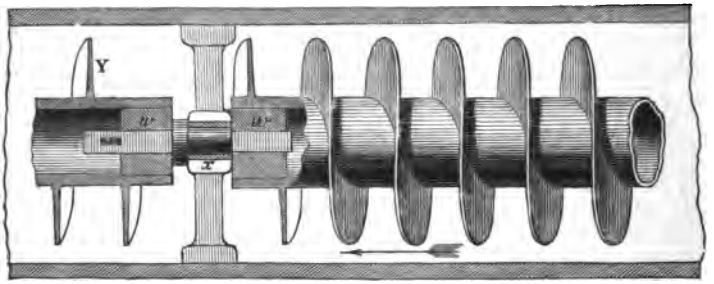
Fig. 261.



frame plates *a*, *b*, bolted together, about a quarter of an inch in thickness, upon which grooves are cast for the reception of the sheet-iron plates *c*, *d*, and *e*, *f*, which are bent to the shape of the frame plates, and inserted in the groove, forming, when the bolts *h*, *k*, are screwed tight, a neat and compact box.

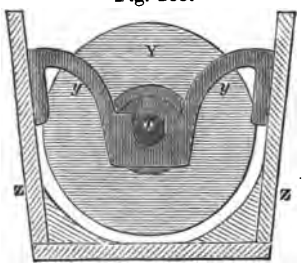
The creeper, fig. 262, is an Archimedian screw worked in conjunction with the contrivance just described, which is applicable to the raising of the grain or flour from a lower to a higher level. For horizontal transport modern millwrights make use of this apparatus, which is an application of a well-known principle for the abridgement of manual labour. This creeper consists of a

Fig. 262.



long endless screw with a wide pitch and projecting thin threads, inclosed in a wooden box or trough, of dimensions slightly greater than its own diameter. It is made to revolve on its axis by means of a belt and pulleys, at a velocity corresponding with that of the elevators, and, being restricted from moving longitudinally, the threads, or rather leaves, of the screw force the grain introduced at one end of the trough to the other. The action of the screw in the case of the creeper is identical in its nature with that of the endless screw in giving motion to a worm wheel.

Fig. 263.



The material employed is cast iron; the creeper is made in

6 feet lengths, each length being in the form of a tube $3\frac{1}{2}$ inches in diameter, and about $\frac{3}{8}$ of an inch thick, with broad leaves or threads cast round it, after the manner of an Archimedian screw. The thickness of the threads does not exceed $\frac{3}{16}$ of an inch at the outer extremity.

The different lengths of which the entire creeper is composed are joined together by short wrought-iron studs *x*, *x*, fig. 264, forming also the journals on which it revolves. These are made with square tails fitted into similar holes formed in the

Fig. 264.

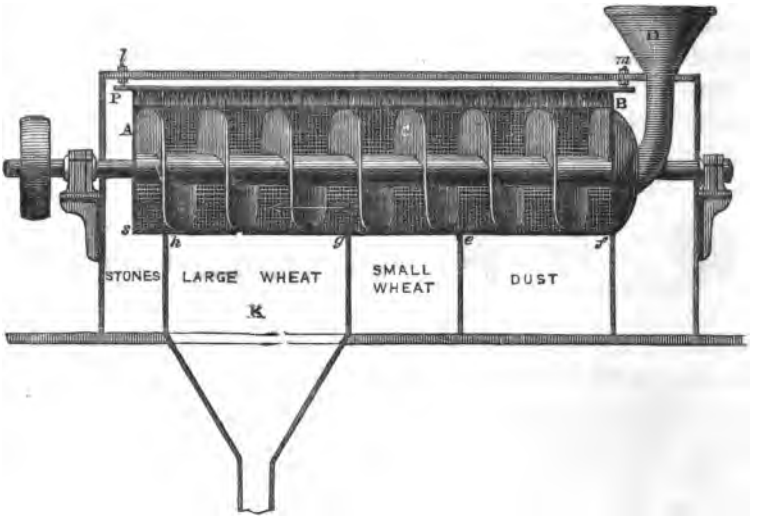
centre of the small cylindrical blocks *w*, *w*, which are carefully turned on their exterior surfaces, and driven into the open ends of the pipes Y Y, figs. 262 and 263, previously bored to the same diameter.

This construction at once insures a strictly rectilinear axis for the entire range, whatever may be its length. The arrow, fig. 262, indicates the direction in which a creeper, constructed in the manner shown in the general view, would propel the grain.

The separator, fig. 265, consists of a wire cylinder A B, divided into partitions by a screw C, with long leaves and coarse thread, through which the wheat slowly travels and keeps falling by its own weight, as it moves forward from one extremity of the screen to the other. The space underneath the wire cylinder is divided into chambers by partitions. From *e* to *f*, in the first compartment, the wire of the cylinder is so close as only to admit of dust passing through; from *e* to *g* in the second, the wire is arranged for only small wheat; and from *g* to *h*, in the third, the large grains of wheat are freely delivered into the spout *k*, from which they are conveyed to the wheat screen. Should there be any stones or large substances in the wheat, they are cast out at *s*. A whalebone brush P B serves to free the machine from all grains of wheat which fasten themselves between the meshes of the wires. As fast as the brush wears away, its position is regulated and maintained by

the adjusting screws *l m*. The cylinder and the screw are connected together, and revolve at a velocity of 20 revolutions per minute.

Fig. 265.

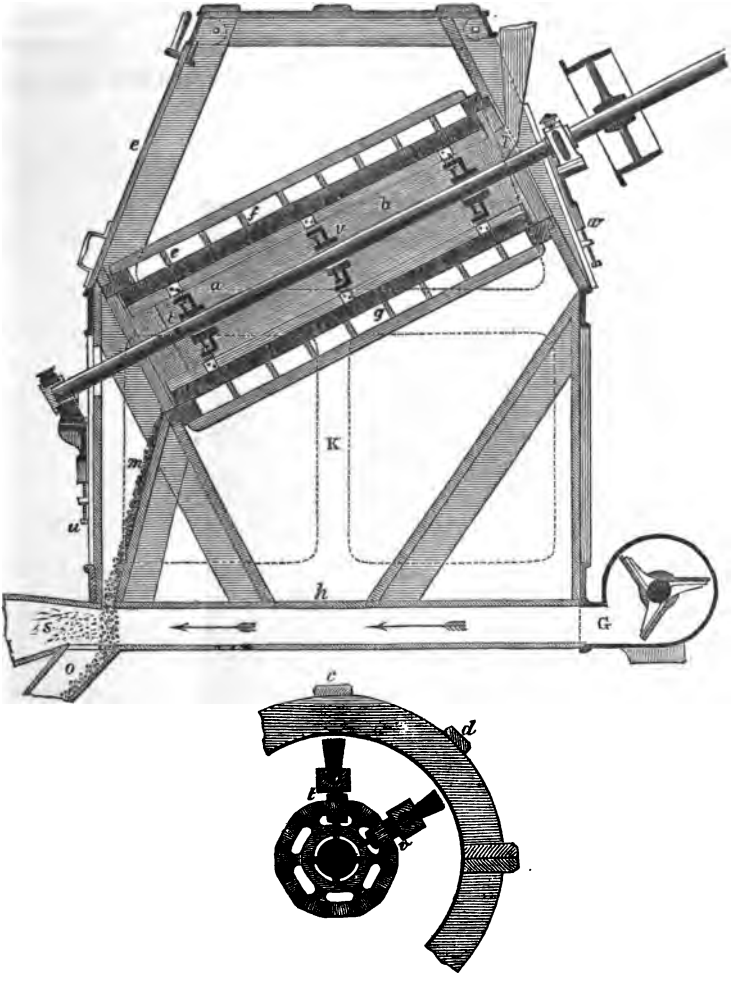


The screening machine is constructed as shown in the drawing, fig. 266. The cylinders *a b* of these machines vary from 4 feet to 8 feet long. The annexed is a small one, 4 feet 2 inches long and 1 foot 4 inches diameter, covered with 6 by 8 wire gauze, and has an inclination of 1 in 2.

Rings of wood *e, f, g*, $\frac{5}{8}$ thick and $2\frac{1}{4}$ deep, are placed round the cylinders at distances of $4\frac{3}{4}$ inches. To bind the rings together, horizontal planking is used, as shown at *c* and *d*, in the transverse section, by reference to which it will be seen that the cane brushes do not touch the wire gauze, but that $\frac{3}{16}$ of an inch clearance is allowed. The brushes revolve in the cylinder at a velocity of from 350 to 400 revolutions per minute, and by this action the corn, which enters the machine by a wooden spout through the opening *l*, is brushed; the dust passing through the wire gauze falls into the close chamber K, whilst the corn travels to the end of the cylinder *a b*, where a spout *m* is fitted for its reception. On its passage from this

spout to the space *o*, it is exposed to the action of a current of air from the fan G, which clears it of dust through the aperture s.

Fig. 266.

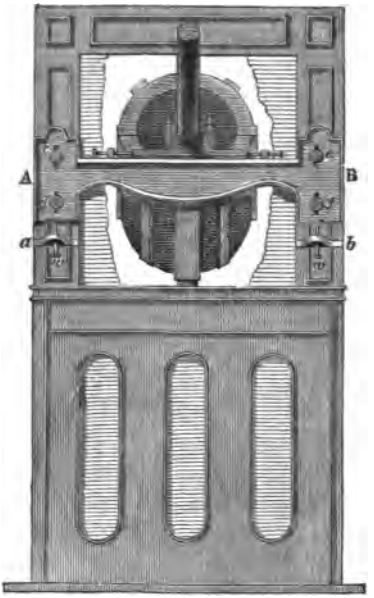


The proper distance of the cane brushes from the wire gauze is maintained, as they wear away, by the screws *t* and *v*, and the shaft on which the brushes are fastened is adjusted by the

screws *u w*; *h* is the dust-hole at the bottom of the machine, 12 inches square, through which the dust is taken as often as necessary from the chamK. [illegible] r *e*, convenient access to the machine is afforded, and the dusting and cleaning rendered easy.

Fig. 267 is an outside elevation of the screening machine, which shows the cast-iron frame lined with wood. The screws *w w*, which regulate the shaft on which the brushes are fixed,

Fig. 267.



are screwed into projections *a b* cast on the frame, and by the slots and screws *c*, *d*, *e*, *f*, the whole of the brackets A B can be raised and depressed as necessity requires.

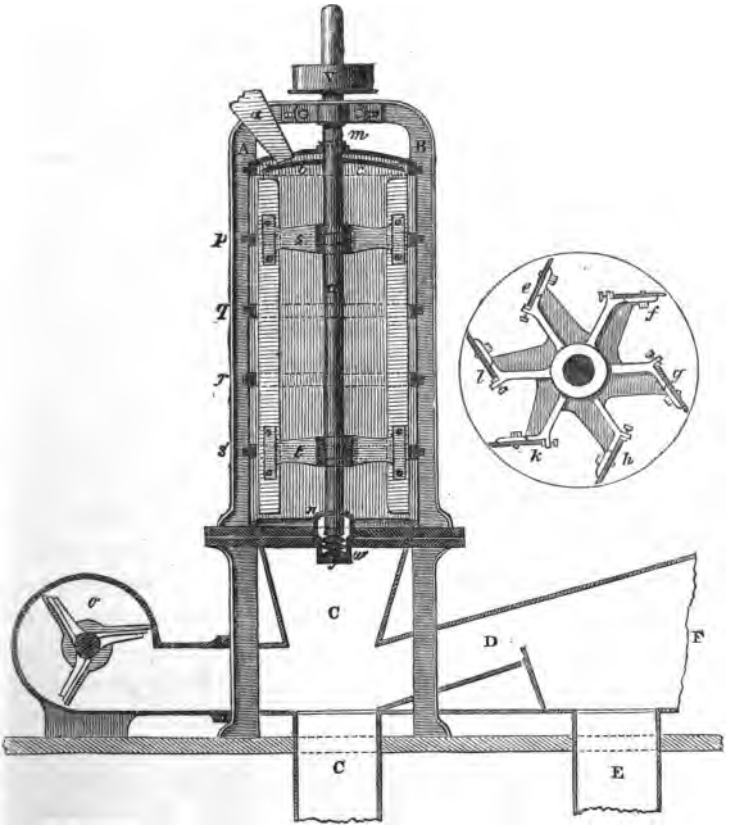
In some mills, besides the separator already described, a smut machine is used.

The corn enters the machine by the spout *a*, fig. 268, and falls upon the cast-iron plate *b c*, which, revolving with the shaft *d*, and the beaters *e*, *f*, *g*, *h*, *k*, *l*, at a velocity of 450 to

500 revolutions per minute, throws the corn to the extremity of the cylinder *m n*, where it comes into contact with the beaters, which, together with the fan *o'*, as the corn passes through, take away the greater portion of the dust and foreign matter. Owing to their not being surrounded by a wooden framing, these machines are placed in a closed room by themselves.

Fig. 268 represents a section of a machine of this kind; the

Fig. 268.



cylinder *m n* is 1′ 7″ diameter, by 4′ 6″ long, covered with 6 by 8 wire gauze, and is surrounded at intervals of 9 inches by rings

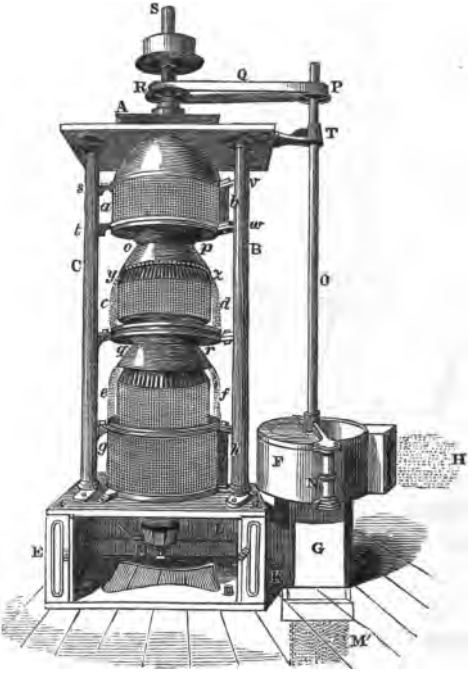
of iron *p*, *q*, *r*, *s'*. Inside the cylinder two arms of cast iron *s* and *t* are placed, and bolted on these arms are six pieces of iron, as shown in the cross section. The arms are keyed on the shaft *d*, which is driven by the pulley V, for the bearing of which circular rings *α*, *β*, *γ* are made and fitted in the box *w*, and the whole is supported by the framework A, B. By the spout C, C, the corn is conveyed to the screening machine, or the millstones, and by the passage D the hollow grain and heavy dust fall into the spout E, and the dust into a chamber at F.

This description of smut machine is the one most in use at present, having completely superseded the American wheat screen.

Another sort of wheat screen or smut machine has been patented by Mr. James Waltworth.

It consists of a number of cylinders *a b*, *c d*, *e f*, *g h*, fig. 269, covered with wire gauze. The outer coating of wire gauze is

Fig. 269.



taken away from the cylinder *c d* and *e f*, in order to show the internal cylinders, also covered with wire gauze and grooved plates. These cylinders are supported by rings of cast iron fastened to the projections *s*, *t*, *v*, *w*, &c., on the cast-iron columns C, B, &c.

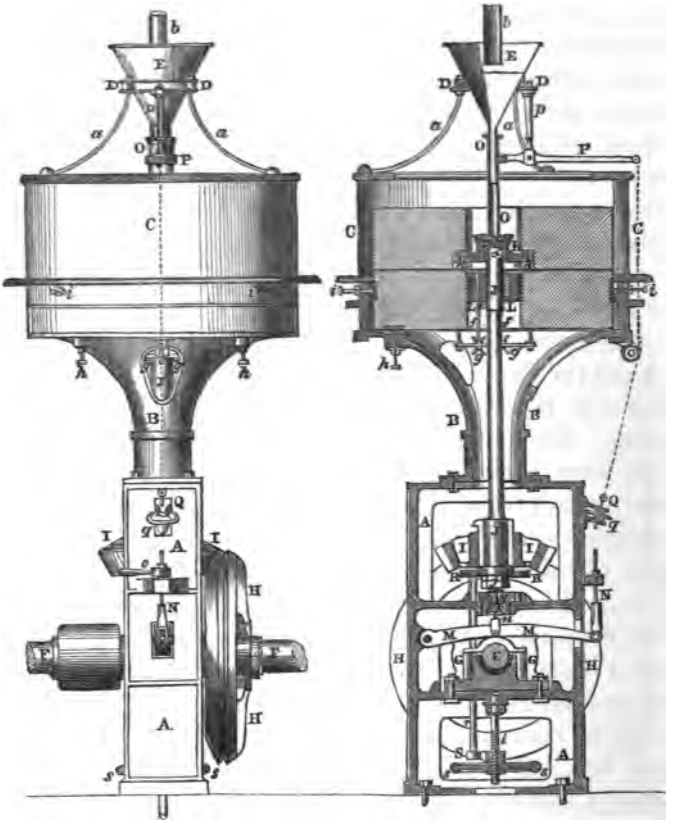
The wheat enters the machine, which revolves at a velocity of 500 revolutions per minute, by the spout A; it then passes between perforated grooved plates in the first cylinder, like those shown at *o p*, *y z*, in cylinder *c d*. After passing through these perforated grooved plates *q r*, where it is scrubbed, the corn descends between the wire gauze of the internal and external cylinder, where (the outward cylinder being stationary, and the internal cylinder revolving) it is exposed to a severer brushing, without, however, injuring the grain. Having passed through all the cylinders successively, it falls into the spout L, and on its passage to the part M′, it is exposed in the box G to the action of a powerful fan F, which draws up all the light grain, dust, &c., and ejects them at H. By the cast-iron box E L, convenient access is afforded to the footstep M. The opening K admits the air under the perforated plate for the fan. N is a pedestal for the fan shaft O, and T a bracket which serves as its bearing. The fan is driven by the pulley P, which is connected by the strap Q with the pulley R, keyed on the shaft S.

The value of this machine consists in the large amount of scrubbing surface over which the corn passes. Slight modifications of this machine are made for Egyptian corn, which is first washed, and then run through the cylinders of the machine.

The Framing.—A cast-iron standard or framing A, A, fig. 270, securely bolted to a stone foundation by two holding down bolts, encloses the principal part of the driving and adjusting gearing for each pair of stones. It is made in the form of an oblong box, and is traversed by two horizontal diaphragms or partitions, cast of a piece with it, the upper one for sustaining the footstep of the mill-spindle and its adjusting apparatus, and the lower for carrying the plummer-block of the driving shaft. It is surmounted by a large bell-shaped casting B, B, called the cone, firmly bolted, by a flange at its lower end, to the standard, while the upper extremity is expanded, and terminates in a cylinder of a diameter somewhat greater than that of the

mill-stones, in which the lower (called the bed-stone) rests, and is secured within it. Two straight and broad flanges are cast at opposite sides of the cylindrical part, for the purpose of bolting the cone to the beams of the mill, or to the same part of the framing of the contiguous pairs of stones; while

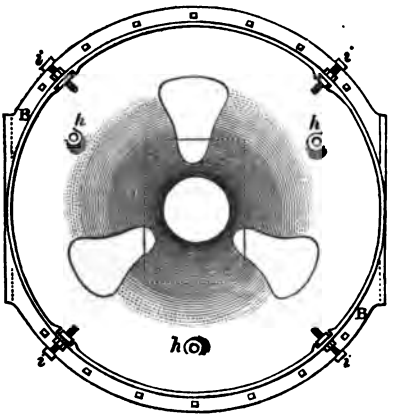
Fig. 270.



another circular flange passes all round, for sustaining the flooring. Three large openings are left in the upper part of the cone to give access to the interior, and it is provided with suitable arrangements for the reception of the several adjusting screws required for the setting of the lower stone.

Fig. 271 represents a plan of the cone, showing the openings and the number and disposition of the adjusting screws above alluded to.

Fig. 271.



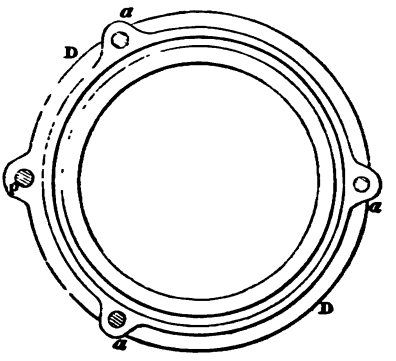
The Stone Case and Feeding-Hopper.—Above the cone, and of the same diameter with the cylindrical part of it, is placed the stone case C, fig. 270, which surrounds the upper stone, and serves to confine the flour which is the result of the grinding. This is simply a cylinder of thin sheet iron, resting upon the stone floor, and having affixed to the top of it a ring of wood, on which the tripod for supporting the feeding apparatus is set. This cover is made open in order to admit the air freely between and around the stones during the process of grinding. A cast-iron ring D D, fig. 270, supported by three malleable iron legs *a*, *a*, *a*, forms a sort of tripod, in which is placed the hopper E, which receives the grain from the garners above, through the feeding-pipe or spout *b*, and supplies it to the stones by means of the feeding apparatus to be hereafter described. A piece of coarse wire gauze is placed in the hopper, to intercept any foreign body that may descend with the grain.

An enlarged view of the ring D is shown in fig. 272.

The Driving Gear.—The driving shaft F, fig. 270, is part of the line of horizontal shafting which is common to the whole range,

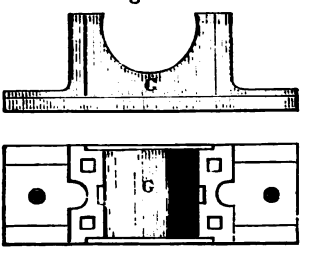
and receives its motion from the prime mover, generally through the intervention of a single pair of wheels. The ve-

Fig. 272.



locity of this line of shafting is usually from 70 to 80 revolutions per minute, with stones of the diameter of those in our examples. The different lengths of which it is composed are connected together by couplings of the same description as that described and represented at fig. 213, page 81 of this work. The shaft F revolves in brass bearings, fitted into a plummer-block G, fig. 273, bolted to a sole formed, as before noticed, in the standard A, fig. 274. The strain of the shaft being entirely in a downward direction, this plummer-block requires no cover, the journal being simply protected from injury by a slight brass cap.

Fig. 273.

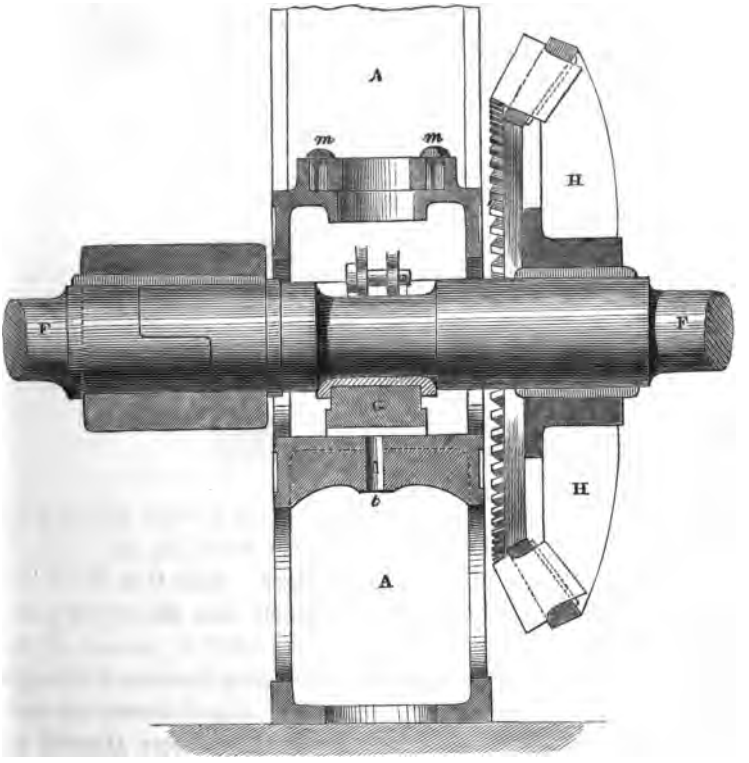


A large bevel mortice wheel H H, figs. 270 and 274, working into the pinion I, on the mill-spindle, serves to transmit the motion of the shaft F to the latter. These wheels are made with the greatest possible care and accuracy, so as to work together very smoothly. The pinion is not fixed immovably upon the spindle, but is capable of sliding vertically upon it by means of a sunk feather.

The Mill-spindle and its Appendages.—The mill-spindle

J, J, figs. 270 and 292, is made of the best forged iron, accurately turned over its entire length, and rises perpendicularly through the standard A, the cone B, and the lower millstone. It is attached to the upper or running stone by means of a cast-iron piece K, figs. 270 and 275, called the rhind, which combines this function with that of regulating and delivering the supply of grain to the

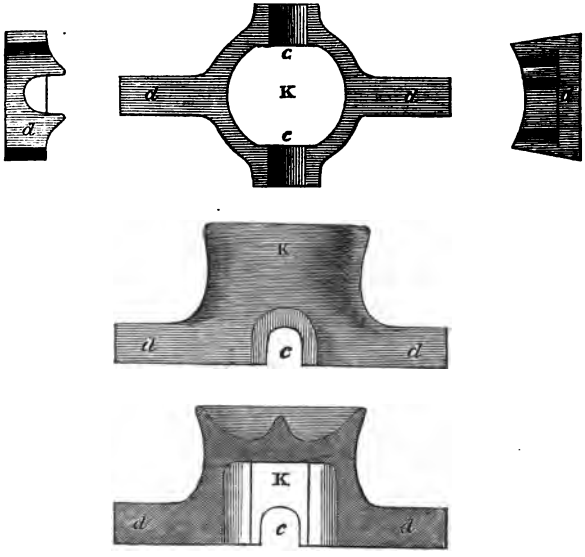
Fig. 274.



stones. It will be observed by the drawings, fig. 275, that it forms a species of universal joint, the small steel cross-head *c c*, on the top of the mill-spindle, fitting into corresponding bearings in the rhind, while the projecting tails *d, d*, cast upon it at right angles to the former, work in similar bearings formed of small cast-iron pieces sunk into the stone. By this arrangement it will be observed that the connection between the mill-spindle

and the upper stone is complete, while at the same time it admits of the free and unconstrained action of the latter against the grinding surface of the lower stone.

Fig. 275.



The lower or fixed stone is perforated by a large square hole in its centre, into which the cast-iron block L, fig. 276, is firmly fixed by slips of woods and wedges. Into this block are fitted the three brass bushes *e*, *e*, *e*, which form the upper bearing of the mill-spindle. These are adjusted by means of the wedges *f*, *f*, *f*, the screwed tails of which pass downward through the ring *g*, fig. 277, and are regulated by thumb screws on each side of it. The large openings in the cone, before alluded to, afford access for the working of these screws. Small semi-circular chambers are formed in the socket L, fig. 276, between each bush, and filled with hemp and tallow for the lubrication of the mill-spindle; and the whole is carefully protected from dust by slips of sheet-iron screwed over it.

The Millstones.—The diameter of the millstones most in use at the present day is 4 feet, and their thickness about 12 inches; one-half of this thickness is composed of French burr, a very

hard, though porous mineral, of a siliceous nature; the other half is made up of plaster of Paris. In consequence of the difficulty of obtaining sufficiently large masses of the French stone, it is usual to construct the millstones in segments, which

Fig. 276.

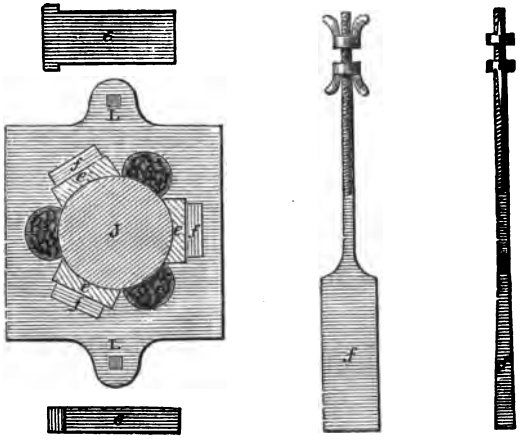
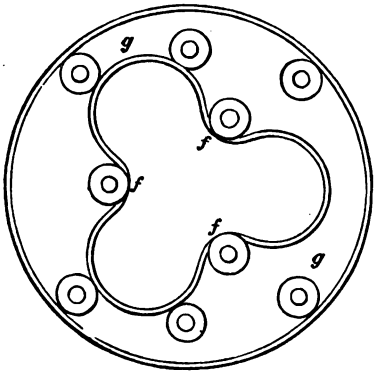


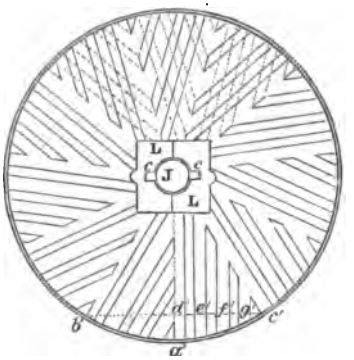
Fig. 277.



are cemented together, and the whole firmly bound by iron hoops passing round the circumference. The lower stone is, in the first instance, carefully dressed into a perfectly flat, plane surface, but the upper one is made slightly hollow for a small

distance from the central aperture, so as to allow the grain to be freely admitted between the stones. Being thus prepared, the circumference of the stone is divided into 11 equal parts, fig. 278; lines are drawn from each division to the centre; these radii determine the limits of the grooves in each compartment. A chord b' c' is then drawn, joining the bounding radii of any two compartments; this chord is, of course, bisected by the intermediate radius J a', in d'. Divide the line d' c' into four equal parts in the points e', f', g', and from these points mark off, on the line d' c', distances equal to the width of the groove to be cut, which is generally from $1\frac{1}{4}$ to $1\frac{3}{4}$ inches wide; then draw through all these points of division lines parallel to the radius J a', terminating them in the radius J c'. These are the outlines of the grooves, which are then to be cut into the stone, perpendicularly on one side, and obliquely on the other, so that each furrow shall have a sharp edge. The direction of the grooves being the same in both upper and lower stones, as they lie on their backs in the position proper for being cut, it is obvious that, when the former is reversed and set in motion, their sharp edges will meet each other after the manner of a pair of scissors (as partially shown by the dotted lines in fig. 278), and thus grind the corn more effectually when it is subjected to the action of the unbroken surfaces between the channels. The land, or portion of stone between each furrow, is cut like the teeth of a file, with from 11 to 18 fine grooves to the inch, at an angle of about 45° with the furrows. A brush is placed on the side of the top millstone to clear the cylindrical cover of the flour at each revolution.

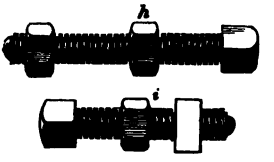
Fig. 278.



Adjustment of the Lower Stone.—It is essentially important to the proper working of any pair of stones, that the grinding surface of the lower stone should be perfectly level, and that its

centre should be exactly perpendicular above that of the lower bearing of the mill-spindle. To secure the former of these conditions, three pinching screws *h*, *h*, *h*, figs. 270 and 279, are fitted into the cone (that number being greatly preferable to four in adjusting the level of any surface), and, bearing against small slips of iron sunk into the stone, it can be raised or depressed by them to any required extent. Fig. 279, *h*, shows the screw for levelling the lower stone on an enlarged scale. The centring of the stone is effected by means of four pinching screws *i*, *i*, *i*, *i*, figs. 270 and 271, acting horizontally upon it. Fig. 279, *i*, shows this screw on an enlarged scale. To secure it against deviating from the truth after having been properly adjusted, all these screws are provided with jam nuts.

Fig. 279.



Adjustment of the Mill-Spindle.—The lower bearing or footstep of the spindle J, fig. 270, is also made capable of nice adjustment, both horizontally and vertically. The former is necessary in order to ensure the accurate working of the driving wheel and pinion, and the latter to regulate the pressure of the upper upon the lower stone, and to compensate for the changes produced upon both by the frequent dressings which their grinding surfaces have to undergo.

Fig. 280.

The footstep *k*, figs. 270 and 280, which is of gun metal, is turned and fitted accurately into a cast-iron socket *l*, resting on the upper diaphragm of the standard A, fig. 270; the hole into which it is inserted, and the annular recess by which it is surrounded, being made of somewhat greater diameter than the corresponding parts of the socket itself. Its exact position is determined and secured by the four radial pinching screws *m*, *m*, *m*, *m*, fig. 281, passing through the ring and working in nuts fitted into recesses cast upon its interior surface, fig. 282.

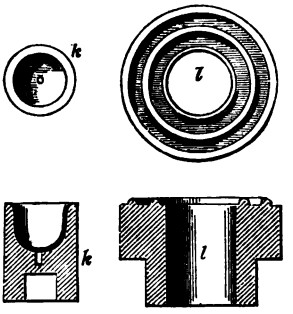


Fig. 281.

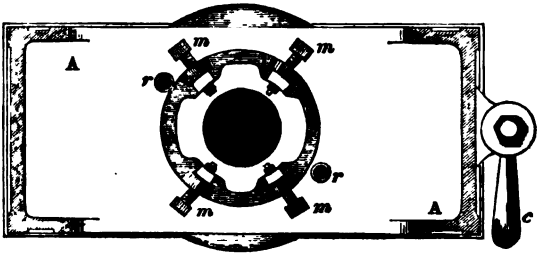
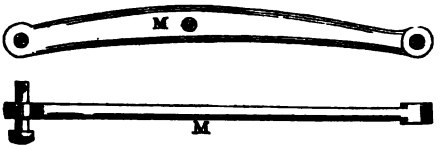


Fig. 282.

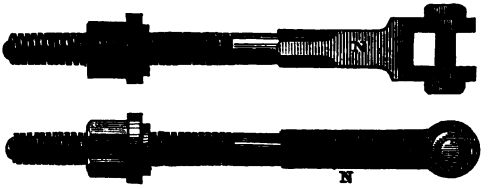
The footstep *k* is not fixed immovably into the socket *l*, but is capable of sliding vertically into it. Its proper position in this direction is regulated by means of a strong wrought-iron lever M, figs. 270 and 283, having its centre of motion in the

Fig. 283.



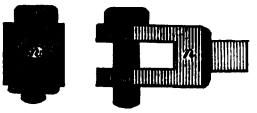
back of the standard A, while its opposite end projects through a slot, and is raised or depressed by means of a screwed rod N, figs. 270 and 284, jointed to it, and passing through a project-

Fig. 284.



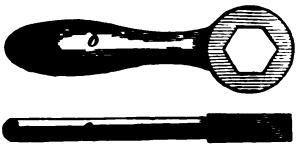
ing shelf cast upon the front of the standard. A small link or saddle *n*, figs. 270 and 285, serves to connect the lever with the footstep *k*; the saddle being provided with a square tail, which is inserted into a similar recess in the under side of the footstep; by which means the latter is prevented from turning in its socket. Thus it will

Fig. 285.



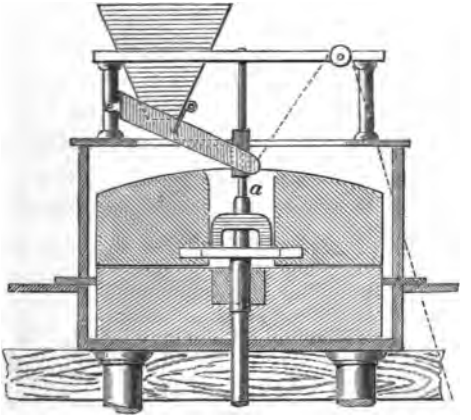
be seen that the entire weight of the upper stone and mill-spindle rests upon the lever M, and that the miller is enabled to vary at pleasure the pressure upon the grain between the stones, and consequently the degree of fineness of the flour produced, by simply turning the nut of the screw N, by means of the key *o*, figs. 270 and 286.

Fig. 286.



The Feeding Apparatus.—By the old process the stones were fed by a clapper, fixed on the top of the running mill-stone, striking the end of a shoe or trough fixed to the under-side of the hopper, through which the grain travelled, when slightly inclined, into the eye of the stone, every time it received a blow from the clapper. An improvement on this primitive apparatus was effected by the introduction of the damsel, formed of an iron spindle with three blades, which acted against the side of the shoe, causing a vibratory motion, and propelling the grain forward in a uniform stream into the eye of the stone, as shown at *a*, fig. 287. The damsel was a

Fig. 287.

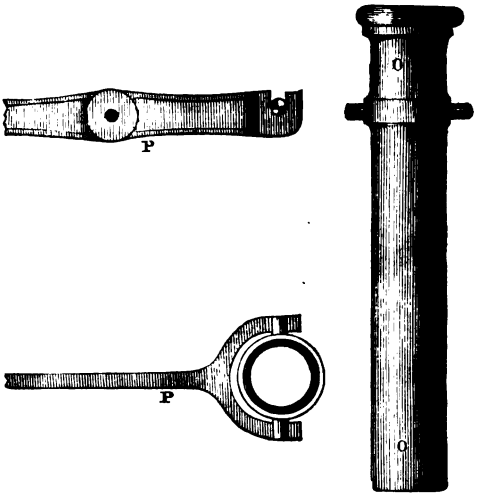


great improvement on the clapper, and continued in general use until the centrifugal or silent feed was introduced.*

* On its first introduction the author had to contend against many opponents, who looked upon the new system of feeding as an innovation. Had it been a patent it would probably have come much earlier into general use.

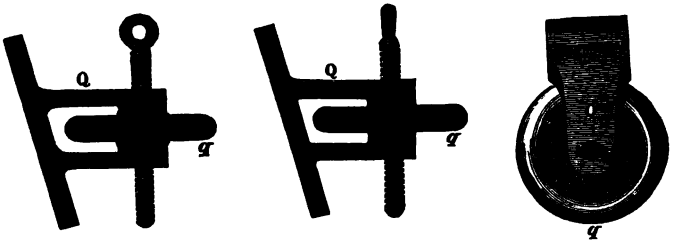
In this arrangement, the supply of grain admitted between the stones is regulated by means of a cast-iron pipe O, figs. 270 and 288, open at both ends, the lower end being brought

Fig. 288.



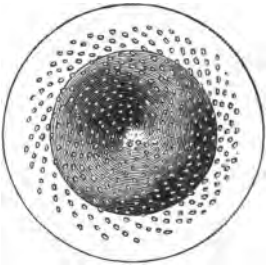
into close proximity with the rhind, while the upper part encloses the pipe in which the feeding hopper E, fig. 270, terminates. It is suspended by means of a cast-iron lever P, which has its fulcrum in the small column *p*, fig. 270, depending from the tripod D. A small chain attached to the end of the lever, and passing over a friction pulley at the bottom of the stone case, serves to connect this feeding apparatus with an ingenious little piece of mechanism Q, figs. 270 and 289,

Fig. 289.



attached to the standard, by which the miller is enabled to regulate the supply with the greatest nicety. This contrivance, as shown in fig. 289, consists of a small hand-wheel *q*, working between the cheeks of a double bracket bolted to the standard A. A small screwed pin forms the axis of this wheel; it passes freely through the cheeks of the bracket, but is screwed into the eye of the hand-wheel, and is prevented from turning with it by means of a feather inserted into the former, and fitting into a groove cut throughout the entire length of the pin, to the upper end of which the chain is attached. By this arrangement it is obvious that by turning the hand-wheel *q* to the right or left, the small pin will be raised or depressed, and through the intervening mechanism, as shown in fig. 270, the size of the opening between the mouth of the feeding-pipe O, and the rhind cup, will be increased or diminished. On slightly raising the tube O, by the lever P, fig. 270, the grain slides along the surface of the cup or rhind K, which, revolving at a rapid motion, discharges the grain with tangential force over the rim of the cup between the runner and the bed-stone. The grain, as it escapes from under the tube, flies off in tangents from the edge of the cup, and forms a beautiful series of curves, as shown in the drawing, fig. 290. At first this system of feeding, like all other improvements, met with opposition from the millers; but the regularity of the supply, and the absence of noise, soon convinced them of its advantages, and paved the way for its general application.

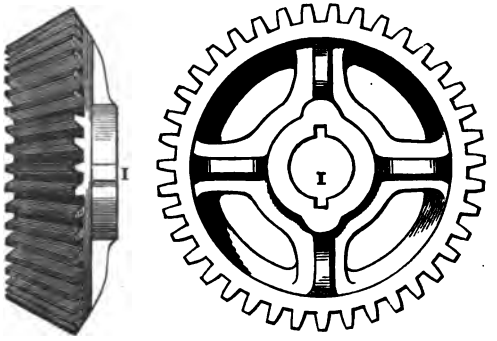
Fig. 290.



The Disengaging Apparatus.—The driving pinion I, fig. 291, is fitted upon the mill-spindle, so as to be capable of sliding up and down upon a sunk feather. When fully engaged with the wheel H, fig. 270, it rests upon a collar formed on the upper surface of a large brass nut *j*, fig. 292, fitted to a screwed part on the lower end of the spindle, and capable of being fixed by a jam nut, by which the miller is enabled to keep the pinion invariably in its proper position with regard to the wheel,

independently of the position of the spindle, which, as we have before had occasion to remark, requires to be slightly lowered

Fig. 291.



every time the stones are dressed. When properly adjusted, the pinion is secured to the spindle by a taper key.

Fig. 293.

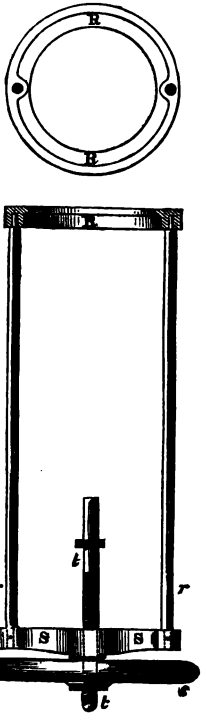


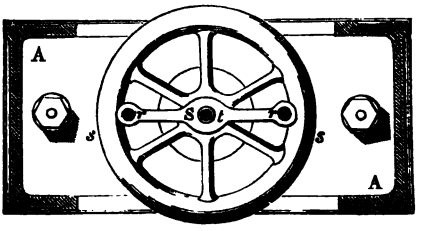
Fig. 292.

It is, however, necessary to throw each pair of stones, periodically, out of gear with the general range, to admit of their being dressed, &c. For this purpose the tapered key is removed, and the pinion raised out of contact with the teeth of its driving wheel, by means of a species of jack or lifting apparatus attached to the standard, the component parts of which we shall now briefly enumerate.

A cast-iron ring R, figs. 270 and 293, supported upon two upright rods *r*, *r*, is brought in contact with the under surface of the pinion by turning the hand-wheel *s*, which is screwed upon its axis *t*, and carries with it in its ascent the cross-head S, into the ends of which the lower extremities of the rods *r*, *r* are inserted. The screw *t* is fixed into a socket cast upon the

under surface of the lower diaphragm of the standard, and the connecting rods *r*, *r*, which pass through holes formed for their reception in both diaphragms; being set in a diagonal direction in order to clear the lever M, and other important parts of the machinery. Fig. 294 is a plan of the hand-wheel and cross-bar.

Fig. 294.



On turning the hand-wheel in a contrary direction, the weight of the pinion again brings it into its working position.

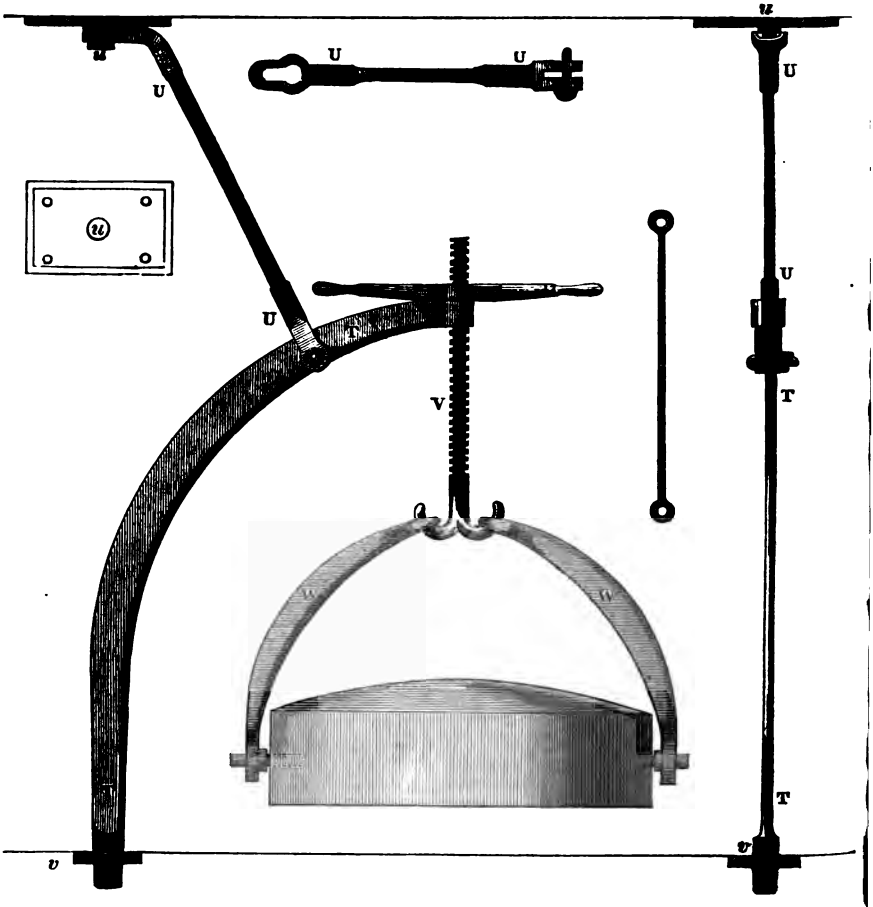
The Stone-lifting Apparatus.

The portable crane or lifting apparatus used for raising the upper stones from their beds, and depositing them on the floor of the mill when they require to undergo the process of dressing, is shown in fig. 295. It consists of a strong malleable iron arm T, T, bent into a form nearly approaching to a quadrant; the lower end works in a cast-iron step *v*, inserted into the stone floor, while its upper extremity is supported by a strong rod U, fitted to rotate upon a stud *u*, fixed into a cast-iron plate, bolted to the beams which support the floor above. The fixed centres, *u* and *v*, are so situated that the machine shall command two contiguous pairs of stones, and the end of the rod U is made of such a form as to admit of its being easily disengaged from the stud; when the entire machine may be removed. A strong screw V, passing through the arm T, and worked by means of a nut formed into a double handle, carries at its lower end the two connecting links W, W, which are attached to the stone by two studs temporarily inserted into it at points diametrically opposite. The links W, W are bent so as to admit of the stone being inverted while it is suspended in the lifting machine. The running stone is retained in its place in the mill simply by its own weight; it is, therefore, only necessary to raise it out of its bearings when the grinding surfaces require examination or repair.

The sack teagle is very simple, and will be readily understood

from the drawing, Plate XIII. It consists of a barrel B′, provided with a rope of sufficient length to reach to the lower floor of the mill, and fitted to revolve in bearings attached to the roof; it receives motion, when required to be brought into action, from

Fig. 295.



a belt connecting the pulley on its axis with a shaft C′, worked by the engine. The length of this belt is so adjusted that the sack teagle may remain at rest, or be set in motion, according as the long lever (the action of which is to tighten or relax the belt as may be required) is raised or lowered. In

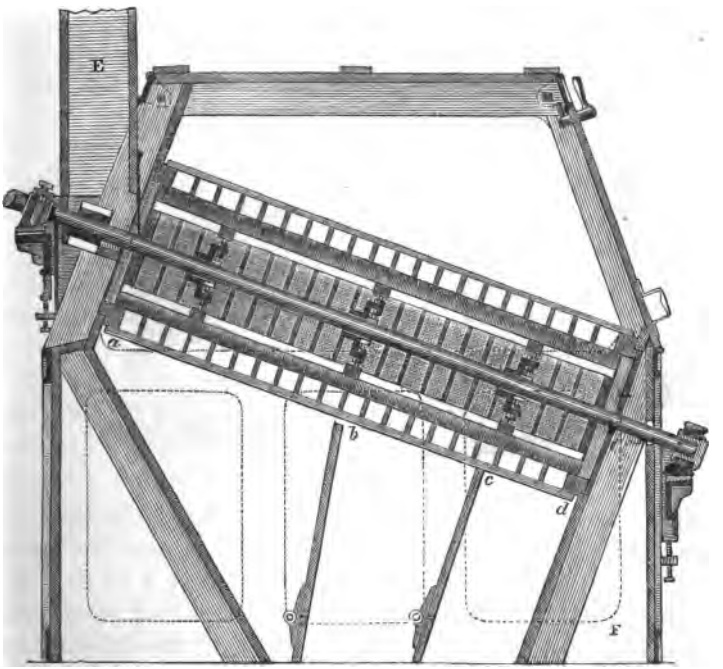
the floors of the mill are formed square hatches or openings, through which sacks, &c., may be admitted; and the rope of the sack teagle passing over a guide pulley situated immediately above the centre of these hatches, thus affords a ready means of raising sacks or any heavy articles to the different flats of the mill.

The Dressing Machine.

After passing the millstones, and having been carried by the creeper and elevator to the third story of the mill, the corn enters the dressing machines; it is here subjected to the last process, and is ready for market.

Fig. 296 represents a dressing machine on a scale $\frac{1}{2}$ inch = the foot; the cylinder 5′·2″ × 1′·4″ is of wire cloth, from *a* to *b* is

Fig. 296.

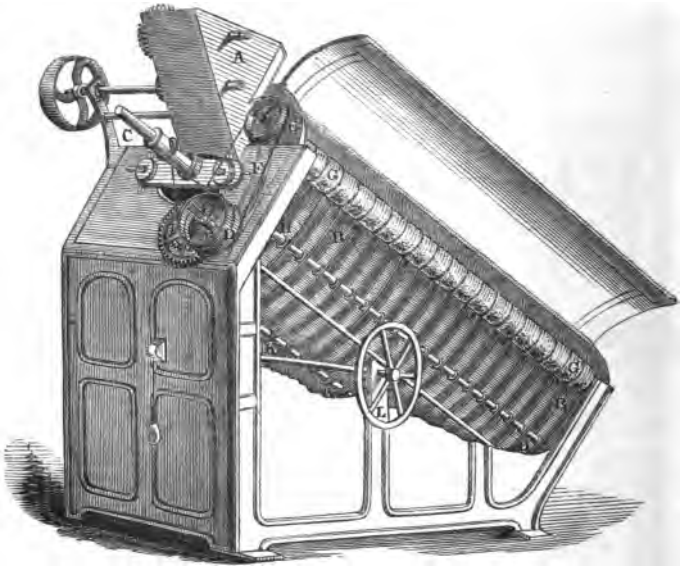


in general up to No. 70 wire gauze, from *b* to *c* is of No. 48 and 50, and *c* to *d* of 30. It seldom happens that wire cloth of

No. 120 wire gauze is used in those machines for the first division, from *a* to *b*, unless it be for the finer description of flour.

An inclination of 3 in 8 is given to the cylinder, and it makes from 560 to 650 revolutions per minute. Rings of wood, $\frac{5}{8}''$ thick, and $2\frac{1}{4}''$ deep, are placed round the cylinder at intervals of $4\frac{3}{4}$ inches, and the whole is bound together by horizontal planking $\frac{7}{8}''$ by $2\frac{1}{2}''$. The same contrivance is used for the adjustment of the brushes and the spindle as in the screening machine; the brushes, however, in this instance touch the wire gauze, and are made of bristle.

Fig. 297.



The ground corn, introduced by the spout E, is brushed first over the finest layers of wire from *a* to *b*, then over the coarser from *b* to *c*, and lastly over the coarsest from *c* to *d*, and is denominated firsts, seconds, and thirds, according as it passes through the first, second, or third divisions of the machine.

That portion of the ground corn which is too coarse to pass through any of the meshes falls out at the end of the cylinder, and is called bran.

Some improvements, of late, have been effected in the construction of wire-dressing machines, by substituting an iron instead of a wood framing; by augmenting the speed from 320 to 500, and even 650 revolutions per minute, and by giving an inclination of 45° instead of 20° to the cylinder.

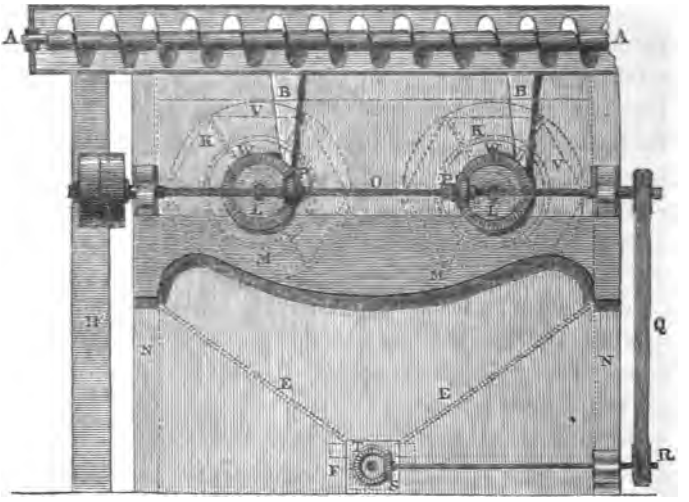
Fig. 297 represents one of these improved iron dressing machines. In its general construction, it somewhat resembles the one already described, fig. 296.

In this machine the ground corn enters the cylinder B B, by the hopper A, containing a patent feed apparatus, which regulates the feed, and thus prepares it for passing through the meshes of the wire cylinder. The internal brushes are secured to the spindle in the same manner as those in the previous machine, fig. 296, but with a different arrangement for adjustment. The speed of the driving shaft is quickly reduced by the spur wheels, which gear into a wheel on the circumference of the cylinder, thus causing the cylinder B B to revolve slowly. The pulley D is connected with the pulley E by means of the strap F, which causes the external brushes G G to revolve, and thus keep the wire cylinder from being clogged up. By an ingenious arrangement with an eccentric, the brushes are lifted off to allow the cross bars H H, K K to pass without injuring them, and are reinstated in their position as soon as ever the bars are clear. By twisting the strap, these brushes are made to revolve in a contrary direction, and thus prevent the bristles from taking a permanent set in one direction, and from wearing away unequally. The space under the cylinder is divided into three partitions, or hoppers, by movable boards, and the distance between them is increased or diminished at pleasure by the hand-wheel L. As in fig. 296, that portion of the meal which does not pass through the wire cloth falls out at the end of the cylinder.

The bolting machines are on the Swiss and American principle. Fig. 298 is an end elevation of a bolting machine, with two cylinders, and fig. 299 is a longitudinal section on a smaller scale. The cylinders K K are from 24 to 26 feet long, and 3 feet diameter, and make from 20 to 22 revolutions per minute. At distances of about 4 feet, radiating rods are inserted in the wooden shaft, which form the reels of the bolting machine, to support the

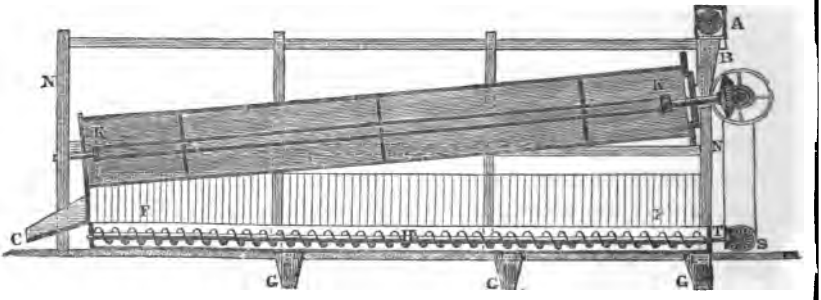
silk covering through which the flour has to pass. The hexagonal wooden shaft terminates in iron pivots which have their bearings in the plummer-blocks L, L, bolted to a cross piece of cast iron M M, which is bolted to the wooden frame-

Fig. 298.



work N N. The machine is driven by a cross shaft O, having two bevel wheels P P keyed upon it, which gear into corresponding wheels keyed on the driving shafts of the bolting cylinders. The cross shaft also gives motion through the intervention of the strap Q to the pulley R, which drives a small toothed wheel S, gearing into a wheel T, keyed on the creeper

Fig. 299.



shaft H, which carries the flour along the trough under the cylinders or reels. It will be observed that the cylinder cover V V is grooved into the end of the cylinder, and moves with the machine, whilst the cover W W is stationary: this enables a constant supply to be given to the machine without waste.

The meal travels from the elevators along the creeper A A, and enters the bolting machine by the hoppers B B; here it makes a progressive onward motion, rising and falling by gravitation from the sides of the reel till the flour has passed through the interstices of the silk and the bran delivered by the spout C at the end of the machine. The flour, after passing through the silk, falls upon the boards E E, fig. 298, and F F, fig. 299, into the creeper H; and in travelling along this creeper, it is received into bags by the spouts G G G. Should any of the meal have failed to pass into the bolting machines, it is carried on to the spout H′, fig. 298, which conveys it to the elevator from which the creeper A is supplied. The finest flour, chiefly used for confectionary and biscuit-making, is dressed and prepared in this way.

The great advantage of this class of dressing machinery is that the silk-bolting machine dresses the flour direct as it comes from the millstones, as the process is slow, and by the repeated rising and falling of the meal in travelling from one end of the cylinder to the other it is sufficiently cool for immediate use, or ready to be hoisted above by the sack teagles, to be sacked for the market.

Messrs. John Staniar and Co., Manchester Wire Works, who supply this class of machinery, have lately constructed the dressing and bolting machines, with an improved feed. The meal is conveyed into a hopper with inclined sides, over which a rake slowly revolves, and as the meal travels several times round before it arrives at the feed-spout in the centre, it is exposed to the action of the air, and freed of the greater portion of its moisture. A piece of coarse wire gauze is placed at the top of the spout to intercept any foreign particles which may accidentally have got into the meal.

REFERENCES

To the General Elevation, fig. 270, *and the Detailed Drawings, fig.* 271 *to fig.* 294.

AA, the standard or lower framing of the grinding machinery.

BB, the cone or upper framing.

C, the stone case, of sheet-iron.

D, a cast-iron ring supporting the hopper, carried upon

a, a, a, three wrought-iron legs, resting upon the top of the stone case.

E, the feeding hopper.

b, a pipe for supplying grain to the hopper from the garners above.

F, the main driving shaft.

G, plummer-block of the shaft F.

H, a bevel mortice wheel, conveying the motion of the shaft F to

I, the pinion of the mill-spindle.

J, the mill-spindle.

K, the rhind of cast iron by which the spindle is connected with the upper stone.

c, d, the bearings of the universal joint formed by the rhind.

L, the bed-stone box for the upper bearings of the mill-spindle.

e f, bushes and wedges for adjusting the bearings.

g, a thin cast-iron plate, by means of which the wedges *f, f* are adjusted and fixed.

h, h, h, pinching screws for adjusting the level of the lower millstone.

i, i, i, pinching screws for it.

j, a large brass nut for supporting the pinion I.

k, footstep of the mill-spindle.

l, cast-iron socket for the footstep *k*.

m, m, pinching screws for adjusting the socket *l*.

n, the saddle or link connecting the footstep *k* with

M, the great lever for supporting and adjusting the mill-spindle.

N, *o*, screwed rod and key for working the lever M.

O, the movable feeding pipe, of cast iron.

P, lever for adjusting the pipe O.

p, small column forming the centre of motion of the lever P.

Q, *q*, apparatus for regulating the feed.

R, a cast-iron ring for raising the driving pinion out of gear with the wheel.

S, a cast-iron cross-head, being part of the same apparatus.

r, r, upright rods connecting the cross-head S with the ring R.

s, s, t, hand wheel and screw for working the disengaging gear.

T, U, V, W, the several parts of which the stone-lifting machine is composed.

u, *v*, the centres of motion on which it turns.

X, figs. 260 to 264 the lower elevator frame.

Y, Y, the creeper of cast iron.

w, *x*, blocks and studs for connecting the adjacent lengths of the creeper.

y, the brackets in which it revolves.

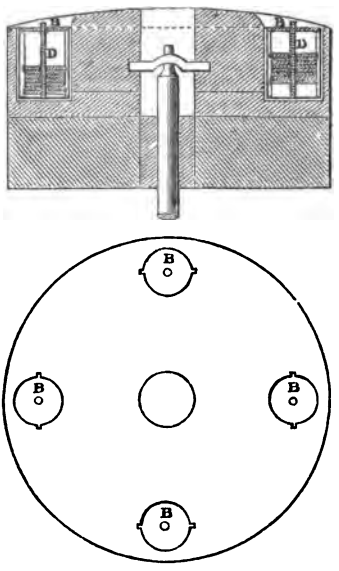
Z, Z, the creeper box, of wood.

Before closing the treatise on flour mills, it may be interesting for the practical miller to know that an ingenious contrivance for balancing the running millstone has been successfully introduced by Messrs. Clarke and Dunham, of Mark Lane, London. Most persons connected with grinding wheat are aware that millstones are built of blocks of French burr, varying in density. These blocks are cemented and held firmly together by iron hoops, as already described; and the back of the stone is filled in with odd pieces of burrs, and backed up with plaster of Paris. The centre or balance-irons, by which the stone is suspended, are then let into the runner; it is immaterial what sort of iron is used for balancing, as any description will do. The usual custom is to suspend the runner on the stone spindle, and balance it with reference to its gravity alone, thus producing a standing balance by adding the required quantity of lead to produce a stationary equilibrium. This was generally thought enough, and the stone considered fit for work. Had the miller, however, raised the runner to an elevation of half an inch from the bed-stone, and rotated it at a speed of from 120 to 130 revolutions per minute, the runner in motion would have dipped or "wabbled" to the extent, on the average, of a quarter of an inch. The effect of this tilting motion when the stones are at work, is to cause unequal pressure and unequal action upon the face of the stones in contact. The cause of this is the effect of the unequal density of the millstone as a whole, causing in motion an unequal centrifugal action in proportion to the denser parts preponderating above or below the plane of suspension.

In order to obviate this evil, there are introduced into the back of the runner four balance boxes, as shown in fig. 300 at BB. These boxes vary in depth from three to five inches, according

to the thickness of the runner; the boxes are fitted with annular weights capable of being adjusted higher or lower, by means of the screws DD, which pass down the centre of the weights. The number of the weights depends on the number required to produce the perfect standing balance. From this it will be seen that the standing balance must be first attained, and then, by raising or lowering the weights in the balance boxes, the running balance is perfectly effected. This is not done by one adjustment only, but by a series of adjustments. Having effected a

Fig. 300.



standing balance, the stone is set in motion, and the dip is found to be on a particular quarter; the stone is then stopped, and the weights in the box opposite to where the dip is are raised higher above the plane of suspension so as to neutralise the variation of the dipping side. This being done, the stones are again set in motion, and the same operation is performed until a perfect balance, at any velocity, is attained. The great advantage of this arrangement is that the weights cannot shift, and the same balance is maintained in good order, and only requires altering with the ordinary wear and tear of the stones.

During the time the first edition of this work was going through the press, I was closely engaged in other matters that required my attention, and prevented me giving that consideration to the system of ventilating the millstones during the process of grinding to which it is justly entitled. Since then I have been more fortunate; and having communicated with Mr. Bovill, the patentee, I am now in a position to give not only a full description of the process, but to introduce all the improvements that have taken place since its first introduction.

On the question of ventilation there has been great difference of opinion as to its efficiency, one party contending that they derived considerable advantage from the process; another, that the powers required to work the fans and connecting apparatus was equivalent to what would grind the same quantity of grain by a proportionate increase of the number of millstones. These assertions do not however seem to agree with the Report of the Committee appointed by the Lords of the Admiralty to inquire into the merits of these improvements as introduced into the Deptford mills. At the close of this report it is stated that "The advantages which Mr. Bovill's apparatus possesses over the present process of manufacturing biscuit meal in Her Majesty's establishments appear to be as follows:—

"*First—Speed in Grinding.* It grinds more than twice the quantity of wheat in a given time with an equal number of millstones.

"*Second—Produce.* It will, with the same description of wheat, produce biscuit meal and flour of a better quality, from having greater life or strength, and in larger quantities; and, according to the Deptford Officer's Report of October 1850, it will produce a better quality of biscuit meal from wheat at 3*s.* 8*d.* per quarter less in value than that usually ground.

"*Third—Temperature.* It delivers the produce from the spouts of the millstones at an average of 20 degrees less temperature.

"*Fourth—Despatch in Dressing.* It dresses the grist into biscuit meal or flour as it comes from the spouts, it being then sufficiently cool for that purpose, and avoids the necessity of sacking the undressed grist from the troughs, and keeping it for several days until it becomes cool enough for dressing.

"*Fifth—Duration of Millstones.* The millstones grind four times the quantity before they require to be re-dressed.

"*Sixth—Cleanliness.* In corn mills conducted in the ordinary manner, the stive (or dust) whilst grinding is excessive, and injurious to the millers; but when this machinery is in operation, no stive (or dust) is produced, and the mill is continually in a state of cleanliness highly conducive to their health and comfort."

After this report (which is signed by Samuel Triscott, *Storekeeper, Royal William Victualling Yard*; Joseph Penhorn, *Store keeper, Royal Clarence Yard*; and T. W. Miller, *Engineer and Mechanic, Portsmouth Yard*), there cannot exist a doubt of its efficiency, and we therefore have no hesitation in introducing the following drawings and explanations, as kindly furnished by Mr. Bovill.

The drawings figs. 301 and 302 represent transverse sections of the apparatus:—

A, the millstones as usually employed; B, driving spindle to which the cup C is attached to receive the grain from the telescopic feed-pipe D, which is regulated in the ordinary manner with the level E. The top of the millstone case is closed by the plate F, which has a nozzle G, provided with a throttle valve H, for regulating the blast to the stones according to the quality of corn being ground, and the condition of the millstones. When the stones are sharp they require less blast than when dull, and damp wheat requires a much greater supply of air than dry wheat. I is a small cast-iron column resting on the plate F, with a shoe on the top to carry the cornhopper J. K, the main air pipe from the fan-blowing machine, which is continued over all the stones. L, the main exhaust pipe from the exhaust fan. M, a flexible mackintosh pipe from air main pipe for conveying the blast to the stones. N, a movable upright exhaust spout for connecting the millstone case to the exhaust main; there is a wood slide o in this pipe for regulating the amount of exhaust. P, a cast-iron ring turned on the face and attached to the top of the running stone around the eye. Q, a circular leather resting on the turned face of the ring P, the top being fixed to the millstone case: this leather ring prevents the current of air or any grain passing otherwise than through the

Fig. 301.

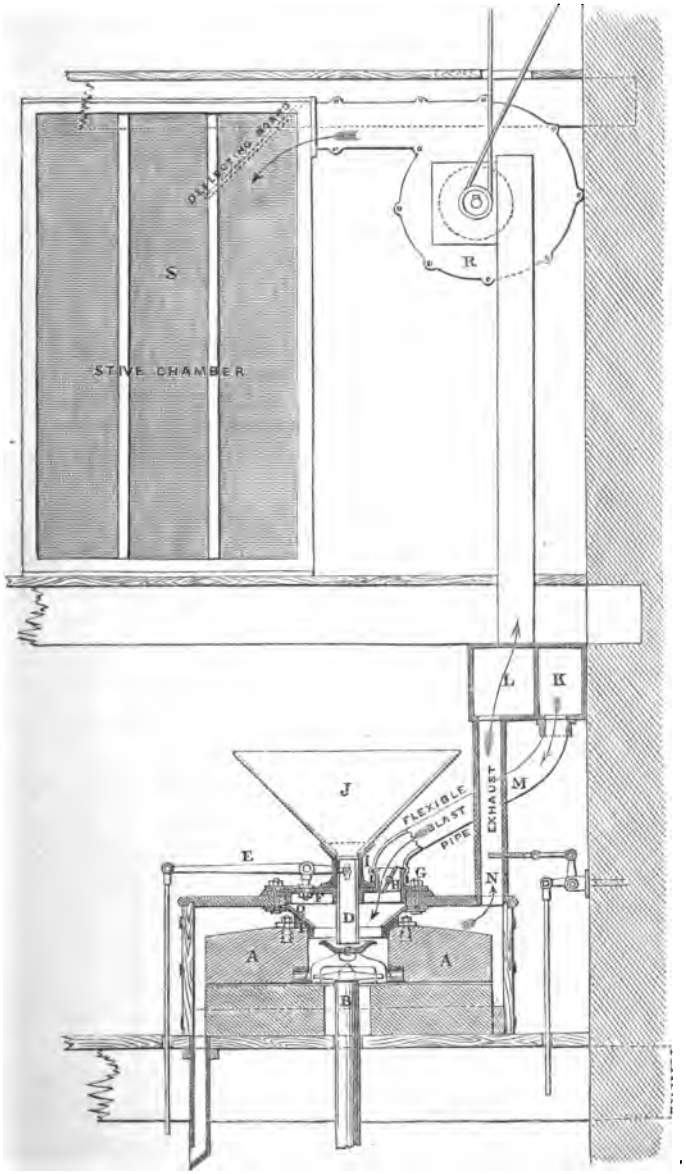
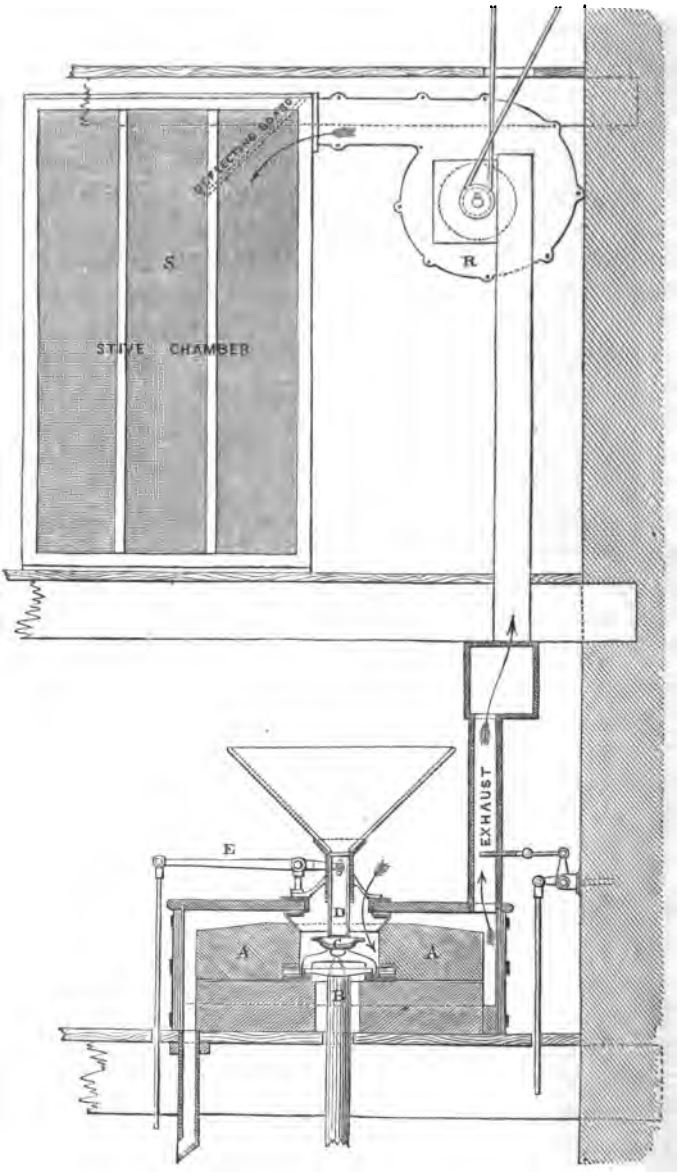

DELIVERING BAND
S
STIVE CHAMBER
R
L
K
J
FLEXIBLE BLAST PIPE
EXHAUST
M
N
E
I
H
G
D
A
A
B

Fig. 302.



centre of the running stone and between the grinding surfaces. R, exhaust fan which discharges the warm dusty air drawn from the millstones into stive chamber S, for depositing the dust. The sides of this chamber are made of a porous woollen fabric, called bunting, through which the dusty air is filtered, the fine particles of flour being retained, and the air passing out clean; this chamber is swept out once in twenty-four hours, and the fine particles of flour thus collected are mixed in with the meal in the usual way.

Fig. 302 shows the arrangement of the exhaust without an artificial blast: the eye of the stone in this case is open to allow air to be freely drawn down the eye of the stone by the natural fan action of the running stone,—the exhaust draws away the plenum of warm dusty air from the millstone case, as in fig. 301.

The advantages arising from the application of this simple and inexpensive arrangement are great, and the millers of most parts of England are availing themselves of the process.

Mr. Bovill states in the first place that it ensures the production of a quality of flour superior in point of strength and colour to any that can be produced by the ordinary process.

"By the old system of grinding, a large quantity of the finest flour is produced immediately; the grain enters the crushing surfaces of the stones, and this is of necessity reground, or rather mashed up with the unreduced particles, until, from the action of the running stone, it is delivered at the outer edge, by which time considerable heat and consequent colour have been imparted to it by the friction of the stones, at the same time that the strength or life of the meal has been considerably impaired, the stones in point of fact having been employed in injuring a large portion of the meal instead of simply doing their proper duty of grinding the unreduced particles.

"By the action of the blast and exhaust machinery, the meal is blown out from between the stones instantly on its being ground sufficiently fine, and in a cool state, leaving the grinding surfaces of the millstones to perform their legitimate office of grinding only the unreduced particles. The stones in consequence with the same power will grind seventy per cent. more corn than on the old system; and with a small additional power the same stones in many mills are grinding from eight to ten

bushels per hour with each pair as against four bushels on the old plan. Damp wheat with the aid of the blast can be ground with ease without any fear of pasting the stones, and the meal is quite cool and dry.

"The exhaust draws away all the warm dusty air from the mill-stone cases, cools the meal, and extracts from it the steamy moisture, and at the same time prevents any dust or stive flying about the mill; the atmosphere of the mill is consequently clear and healthy, and there is a saving of waste.

"The meal comes from the meal spouts perfectly cool and dry, and the millers using this system, almost all dress the meal direct from the stones, through the fine French silk machines, which the patent process enables them to use at all seasons of the year with great advantage.

"The flour from not being overground is stronger and better, and will make more bread per sack than flour manufactured by the ordinary process from the same wheat: all flour manufactured on the old system is more or less overground.

"The millers can nearly double the grinding power of their mills by the adoption of this process, and by which the cost of manufacturing a quarter of wheat is reduced nearly one-half."

Such is the description given by Mr. Bovill of this process, which I have considered necessary to transcribe in order that the reader, millers, and those interested may judge of the advantages of this important process, and avail themselves of this system of grinding whereby the quality of the flour is improved and the quantity greatly augmented.

CHAPTER III.

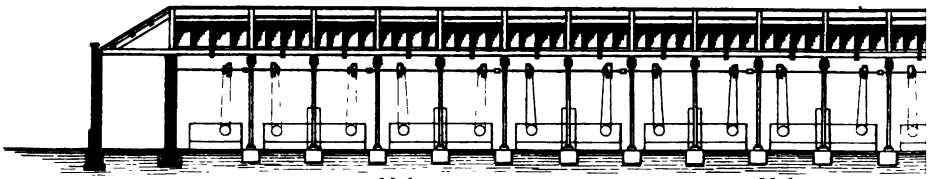
COTTON MILLS.

In our attempts to illustrate the improvements that have taken place in mills and mill-work we have endeavoured to give in detail the present improved state of the machinery for grinding corn, and the next — after what is generally called the staff of life — is the factory system for the manufacture of cotton. Of all the manufacturing interests which the industrial resources of this country present, this is probably the most important, not even excepting the iron and coal trades, and we may readily be excused if we briefly glance at the increase and immense extent to which this manufacture has attained until suddenly arrested by the unnatural war now raging in America. It will be in the recollection of most of our readers, that for the last seventy or eighty years, the mills of Lancashire and those of other parts of Europe, depended almost entirely for their supply of cotton upon the Southern States of America, and that the extension of the trade grew up with the facilities of obtaining the means of supply; and although India, Egypt, and other countries, of late years cultivated and exported cotton, yet the chief dependence of Lancashire and other parts was upon the American States. The present miserable war has, however, cut off those supplies, and hence follows the distress and misery which have from this cause overtaken our once comfortable, willing, and industrious population. Our business, however much we may regret this circumstance, is not with the growth or supply of cotton, but its manufacture, and we have now to describe the improved methods and systems adopted for giving motion to the various intricate and ingenious machines now in use.

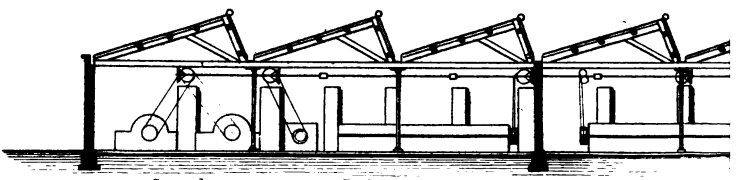
Until of late years, nearly the whole of our cotton mills were built from five to eight stories in height, with a succession of flats or floors in which the different processes were carried on. Generally speaking, the ground or first floors were appropriated to carding, drawing, and roving, with a separate building for the opening and blowing machines, and these constituted the preparatory process. The rooms above were invariably set apart for spinning, by mules if for fine yarn, but by throstles and mules conjointly if for coarser numbers.

This was the state of the factory system thirty years ago when adapted exclusively for spinning, but the introduction of the power-loom and self-acting mule gave a new character to the dimensions and form of factory buildings. In the first instance, it was found that power-looms worked better on the ground-floor than those on the upper stories, and that the yarn required a certain degree of moisture to weave freely, which could not be obtained from the heated and dry floors above. These properties peculiar to the ground-floor led to the shed principle, and there is scarcely a cotton mill now in the kingdom where looms are employed that has not a shed attached to the lower story on a level with the ground-floor. Again, it was found after the introduction of the self-acting mule that one man could work, with the assistance of two or three boys, 1,600 spindles with as much ease as he could work 600 spindles by the hand mules. This led to mills of double the width of the old ones, the former reaching from eighty to ninety feet wide. The spinning mills of the present day are therefore more like square towers or large lanterns, with considerable architectural pretensions as compared with the uncouth buildings we have already described. To these square buildings it is usual to attach a weaving shed with all the requisite warehouses and appurtenances for carrying on that additional department of the manufacture.

In order to exemplify our description of a cotton mill, with the steam engine and transmissive machinery by which it is kept in motion, we might have chosen some of our largest establishments upon the principle referred to above; but having constructed mills for the colonies on a different principle, we have selected for illustration one of those erected in India,



Mules Mules



Cards Bobbin frames

where the whole of the machinery is on the ground floor, and where it is covered by a light roof on the system of the weaving shed for looms. Messrs. William Fairbairn and Sons have built several of these mills for the Bombay Presidency, and the whole of the machinery being open for inspection can the more easily be traced from the opening of the cotton bales to the finished cloth on the opposite side of the mill.

Description. In the annexed plan and sections it will be observed that the building covers a large space of ground, and is chiefly adapted for the country or small towns where land is cheap. In large cities such as Manchester, buildings of this description are seldom erected, owing to the high price of land and local taxes, from which the country is free; we have therefore most of our cotton mills in the surrounding districts, depending on Manchester as a centre and ready market for the sale and the export of yarn and cloth.

The mill to which we refer, shown in Plates XV. and XVI., was built for India, and is now in successful operation some short distance from Bombay.

Plate XVI. is a plan of the buildings showing the position of the machinery and the steam engines at A. The main shafts and gearing are supported on stone or brick pillars through the whole length of the building, receiving in their passage motion from the large pinion at B, which works into the fly-wheel, distributing it to the different lines of shafting on each side.

The steam is supplied to the engines by six boilers, 5 feet 9 inches diameter, and 32 feet long, with internal flues. The engines are each 80 horse-power, collectively 160 horses, 6 feet stroke, 24·7 strokes per minute, and are calculated to work to the full extent of 600 indicated horse-power. The main shafts, which receive motion from the fly-wheel, make 80 revolutions per minute, and are 8 inches diameter for a distance of 70 feet over the throstles and mules, and for a further distance of 35 feet towards the cards, they are $6\frac{1}{2}$ inches diameter, when they gradually taper in both directions to 5 inches at the end over the cards, and to $4\frac{1}{2}$ inches over the looms. The cross shafts over the power-looms are $2\frac{1}{2}$ inches diameter, tapering to 2 inches at the end. The cross shafts over the throstles and mules are $3\frac{1}{2}$ inches diameter, tapering to $2\frac{1}{4}$ inches at the

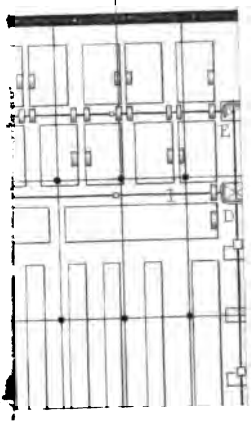
extreme end. Over the slubbing frames and cards they are 3 inches diameter, tapering to 2 inches, the same proportion being observed in the ratio of the power delivered in other parts of the mill.

The cotton is taken from the cotton store, Plate XVI., and is mixed and sorted for the opening machines at G, where it is thoroughly cleaned, and driven about at great velocity, and freed from husks or seeds where it has not been properly ginned. From this it passes in a fleecy form to the scutchers H, where it is carefully spread upon a travelling cloth in front of the machine, and is carried forward to fluted rollers, by which it is conveyed in uniform thickness to the cylinder containing the beater with three or four arms, which makes about 1,600 revolutions per minute, or travels at the rate of 5,000 feet in the same time. Here it is driven forward into a cylindrical wire case, where it meets with a strong blast of air from a fanner which blows off all the light dust, whilst all the heavier earthy particles fall through the meshes of the wire into a receptacle below prepared for that purpose.*

Most of the improved blowers have two beaters, so that the cotton undergoes a thorough cleansing and opening before it is drawn from the wire cylinders and wound on the large bobbins or beams which form it into a lap ready for the cards. From the blowers the laps are conveyed through the door *a* to the cards, where the object is to clean and straighten the fibres and lay them parallel to each other. This is accomplished by unwinding the laps as they come from the blowers by fluted rollers which bring the cotton in contact with the teeth of the large carding cylinder and the covering flats also lined with teeth. In this way it is carded as the cylinder revolves, but not without being intercepted by the teeth of the flats and rollers, which nearly touching the main cylinder, the cotton is unable to pass without being combed and the filaments straightened in the direction of the two-teethed surfaces as they meet each other. After passing through a succession of these flats and rollers, it is taken from the main cylinder by the doffing cylinder, which latter is finally stripped or cleared by a piece

* The scutcher, or blowing machine, is the counterpart of the corn-thrashing machine invented by Andrew Mickle of East Lothian.

NG COMPA



...ely ... from on the surface of another, without risk

of thin steel, reciprocating by a crank motion on the surface of the cylinder, which forwards the cotton in a fine transparent sheet through a tube to the drawing rollers, where it is wound in circular coils into a can in the shape of a narrow band called a sliver.

From the cards it is removed in the cans, when filled, to the drawing frames, which consist of a series of rollers on cast-iron frames, in the line shown at I, I in front of the cards, and these rollers are so arranged that the front rollers run about four times the speed of the back ones, and from this increase of speed it will be seen that the back rollers, whilst they are delivering at a uniform rate, the front ones are rapidly drawing out the fibres, and delivering them in a form greatly attenuated to a much smaller sliver than that which first passed between the back rollers. These rollers require to be placed at the proper distance from each other, in order to correspond with the kind of cotton used, and the length of the fibre or staple, as it is frequently called. The object of drawing is to render the whole of the fibres as smooth and parallel as possible, and in the process of drawing, as many as from five to six or more slivers in cans are run into one pair of rollers from the cards, and these again are frequently multiplied, drawn and redrawn, according to the quality of the yarn required, before they are fit for the slubbing or roving frames, which is the next process.

The slubbing or roving frame is one of the most ingenious contrivances in the cotton trade, as it not only draws the fibre and elongates the sliver on the same principle as the drawing frame, but it gives it a certain amount of twist, and winds it on a bobbin. For a long series of years this was a difficult process, as the delivering and the twist being the same at all times from the rollers, it requires to be wound on the bobbin one layer upon another, neither too hard nor too soft. If the former, the roving will not wind off the bobbin without breaking; and on the other hand, it must not be too soft, otherwise the fault would be equally objectionable as regards the quantity the bobbin should contain. The great secret therefore is to have it neither too hard nor too soft, but a medium degree of tightness, calculated to hold the exact quantity, and unwind itself freely one layer from off the surface of another, without risk

of breakage. This would appear to be a desideratum (in every description of spinning), and to obtain this object with accuracy many ingenious contrivances have been adopted, amongst which we may enumerate sliding straps on conical drums, calculated to the increased circumference of the respective layers as they are wound on, and thus to gain the required degree of tension and compression, as the bobbin continued to increase in diameter, or as each superincumbent layer was wound on. The most important improvement of the roving frame was, however, accomplished by the introduction of the differential motion, which beautiful piece of mechanism effected the object of retarding the motion of the bobbin in the ratio of the increased diameter as it continued to enlarge. This motion gave great exactitude to the process, and enabled the spinner to prepare his rovings with a much greater degree of precision, and in shorter time. After roving, the cotton undergoes a precisely similar process, by passing through what is called a jack or a finer roving frame. In this it is again drawn with additional twist, and again wound on to similar but smaller bobbins, ready for spinning into yarn, either by the mule or the throstle, as the case may be.

The above description completes, as far as our limits will admit, the preparatory process, until the rovings are in a condition to be handed over to the spinner, to be converted into yarn. Before describing the subsequent processes, we must, however, advert to a most ingenious machine for combing the cotton in place of carding it. This machine was introduced into this country some years since from Alsace, in France, and its operations are performed with such exactitude and precision, as to enable the spinner to produce a superior quality of yarn from an inferior quality of cotton. This machine has received great improvements since its first introduction, from the hands of Messrs. John Hetherington and Co., who have changed several of the motions, introduced others, and rendered it available for the finer descriptions of yarn. It is also extensively used in the preparation of wools of every description, but more particularly those of the alpaca, mohair, &c., as also in the preparatory process for flax, to which we shall subsequently have to refer.

To those familiar with the manufacturing districts the process of spinning is well known, but to the general reader who is not acquainted with those districts, a short account of the two different processes may not be uninteresting. There are two modes of spinning: one by a machine called the throstle, the other by the mule. During the early stages of cotton spinning, the cotton was carded and formed into slivers or rovings by hand cards. They were then placed on a wooden frame behind a row of spindles, fixed in a movable box, which travelled on wheels, and these again received motion from a wheel and band, and the rovings which passed from the board behind, and delivered by rollers to the spindles, were held fast, as the spinner drew the spindles from the rovings to the extent of the stretch; and thus by consecutive movements the rovings were stretched and twisted, and every time the travelling frame was pushed back to the rovings, the yarn previously spun was wound upon the spindles. This was the only method in use before the time of Arkwright, who introduced the cylindrical cards and the water frame, or, as it was subsequently called, the throstle, the noise of the numerous spindles imitating the notes of that bird. It was also designated the water frame, from the circumstance that it could not be worked by hand, but required the power of water to give it motion.

The next process is the throstle, which is on the same principle as the roving frame, but with this difference, that the spindles are smaller and more numerous, and range in rows of 150 or 200 on each side of the frame. It has also this peculiarity, that the bobbin which re-winds the yarn as it is spun is not regulated by the differential motion, but the thread, as it is drawn and twisted from the rollers, is wound on by friction as the frame in which the spindles are fixed rises and falls the length or depth of the bobbin. In this operation it is not necessary to wind the thread on to the bobbin slack, as there is no danger of the layers separating, and the friction given to the bobbin is therefore sufficient to fill it hard and tight.

The rovings are also carried to the mule, which is a totally different machine to the throstle; it has no movable frame or spindles with bobbins rising and falling; in fact, it is more

like the spinning jenny, with a travelling carriage which contains the spindles, and stretches out from the beam or stationary roller frame, after the manner of the jenny already described. It, however, combines part of the throstle as well as the jenny, and hence its name of the mule. The mule as left by Crompton possesses many advantages that do not belong to the water frame. It can spin yarn of any degree of softness, and of the finest quality; and since it was made self-acting, it forms its own cop on each spindle, and puts up the carriage, which on former occasions had to be done by hand. These are considerations of vast importance in spinning; and the mule has now attained such perfection that 1,000 spindles can be worked in one carriage with the same certainty and ease as one-third the number could formerly be worked by hand. There is another peculiar property in the mule, and that is the double twist in fine numbers which the yarn receives after the full extent of the stretch is made. When the spindle carriage arrives at this point the rollers become stationary, the motion of the spindles is increased, and the twist required is given according to the quality or purpose for which the yarn is intended. I believe the introduction of the double twist motion is due to the late Mr. John Kennedy, one of our earliest and most successful mule spinners.

Having thus traced the different processes from the bale of cotton to the yarn, our next duty will be to notice the operations of weaving from the yarn into cloth. In our endeavours to accomplish this it will be necessary to glance at the state of the manufacture as it existed previous to the introduction of the power-loom, and to show the advantages attained and the enormous increase which these inventions have produced.

From the earliest historical period, the hand-loom has been in use for the purpose of weaving. That of the Hindoos and all other nations have been of the same character, and until the improvement of the flying shuttle, introduced by Kay, we may consider the loom a primitive and unchangeable machine. It is upwards of thirty years since the power-loom was first introduced. After repeated attempts by Major Cartwright, Mr. Shorrocks, and others, to render it available and self-

acting, it fell into other hands. These attempts were at first discouraging, but after repeated changes, suggestions, and improvements, it ultimately succeeded in producing a cloth more uniform in character and superior in quality to that of the hand-looms. The result of these improvements was a total change in the cotton manufacture. The hand-looms were thrown out of use, and the hand-loom weavers, who were unable to meet the new state of things, were thrown out of work, and suffered for many years the greatest and most distressing privations. By this transfer from hand to power weaving, the whole system of manufacture was changed, and the manufacture of yarn into cloth was no longer carried on in the domestic cottage, but became a part of the factory system. Large shed buildings were erected for that purpose, and the weavers, chiefly girls, were employed under regulations the same as those in the other parts of the mills.

Before yarn can be woven into cloth, four distinct processes have to be gone through—viz., warping, winding, beaming, and dressing—to prepare the warp for the loom. The first of these, the warping, consists of a large vertical reel, on to which the yarn is wound from the bobbin in measured lengths, several of which, when put together, constitute the warp. It is then, for some qualities of cloth, sized or run through a cistern of liquid flour and water, at nearly the boiling temperature, and from this through rollers which squeeze out the surplus fluid, and leave the yarn saturated with the glutinous substance of flour and water, called size. In this state, when partially dried, it is transferred to the loom, where it is woven into cloth. The other process requires more careful manipulation, as the warps have to be formed by winding the yarn from the cop, if it be mule yarn, and from the bobbin if throstle, on to a roller called a beam, and in its passage it is run over a roller about twenty inches diameter, through the divisions of a reed formed of wire, to separate the threads and lay them parallel on to the roller beam.

This done, four or six of the first windings are united on the dressing machine KK, where they are again passed through reeds at each end, and finally wound upon a large bobbin or beam ready for the loom. In its passage from each end of the

machine, it must, however, be observed that it is well brushed or dressed with a pulp of prepared flour and water, which is laid upon the warp, as it passes from the rollers at each end to the beam at the top of the machine, ready for the loom.

The power-loom, although simple in its operations in the first instance, comprises at the present time many important improvements for the manufacture of twills and figure weaving. The revolving shuttle-box, and the changes in colour and form that may be effected, enable it in many cases to compete with the jacquard loom. Many of the beautiful fabrics of mixed goods are woven in this manner, and, judging from what has already been done, we may reasonably look forward to still greater improvements in the quality, as well as the quantity, of cloth produced.

It might have been desirable to have noticed the progressive increase of this important branch of industry; but when it is known that a sum exceeding 70,000,000*l.* sterling represents its annual value, we have said sufficient to impress the reader with a desire for its maintenance and cultivation.

We close the chapter on cotton mills with a list of the most approved speeds of the different machines, and a list of wheels, speeds, &c., as now in operation in the mill of the Oriental Cotton Spinning Company:—

SPEEDS OF MACHINES.

Description of Machine	Diameter of Pulley	Number of Revolutions per Minute
	inches	
Opener or beater	12	800
Scutcher	7½	1,600
Rollers	21	270
Cards	18	130
Grinding machines	12	200
Drawing frame	12	226
Slubbing „	13	235
Roving „	11	415
Throstle „	10	562
Winding „	9½	180
Beam-warping	14½	50
Tap leg-sizing	13	210
Mules	16	232
Looms, $\frac{9}{8}$ wide	12	140
Looms, $\frac{7}{8}$ wide	11	160

Description of Gearing	Driver		Driven	Result
	Diameter	Revolutions	Diameter	Revolutions per Minute
	ft. in.		ft. in.	
Spur fly-wheel . . A′	23 4	24·7	7 3¼	80 revolutions of main shaft.
Bevel wheels, A A A A A A A A	3 0	80	1 11	120 revolutions of cross shaft over looms.
Mortice bevel wheels B B B	4 7¼	80	2 3¾	160 „ „ „ spinning.
„ „ G′	4 8⅓	80	1 7⅝	231·1 „ „ „ roving and slubbing.
„ „ D	4 0½	80	1 10¾	173·3 „ „ „ drawing and blowing.
„ „ E	3 6	80	2 3	124·4 „ „ „ carding frame.
„ „ E	3 8¾	80	2 0½	„ „ „ carding frame.
Pulley . . . . . *a*	3 0	173	1 8	310 „ counter shaft for opener.
„ . . . . . *b*	2 7½	310	1 0	800 revolutions of opener.
„ . . . . . *c*	3 0	173·3	1 4¼	385 „ counter shaft for scutchers.
„ . . . . . *d d*	2 7½	385	7½	1,600 „ scutchers.
„ . . . . . *e*	2 10	173·3	1 9	270 „ rollers on double scutcher.
„ . . . . . *f*	1 3	138·5	1 9	275 „ rollers on single scutcher.
„ . . . . . *g g g g*	2 10½	160	10	560 „ throstles.
„ . . . . . *h h h*	2 0	160	1 4	232 „ mules.
„ . . . . . *i i i*	1 7¾	231	11	415 „ roving frames.
„ . . . . . *k k k*	1 1¾	231	1 1	235 „ slubbing.
„ . . . . . *l l l*	1 4	173	1 0	226 „ drawing.
„ . . . . . *m m m*	1 7	124·4	1 6	130 „ cards.
„ . . . . . *n*	1 7	124	1 0	124 „ grinding machine.
„ . . . . . *o*	11	160	9½	160 „ winding machine.
„ . . . . . *p*	1 0	120	1 0	140 „ looms, 29⅝ wide.
„ . . . . . *q*	1 0	120	11	160 „ looms, 25⅝ wide.
„ . . . . . *r r r*	6	120	1 2½	120 „ beam-warping.
„ . . . . . *s s s*	1 11	120	1 1	120 „ tap leg-sizing machine.

CHAPTER IV.

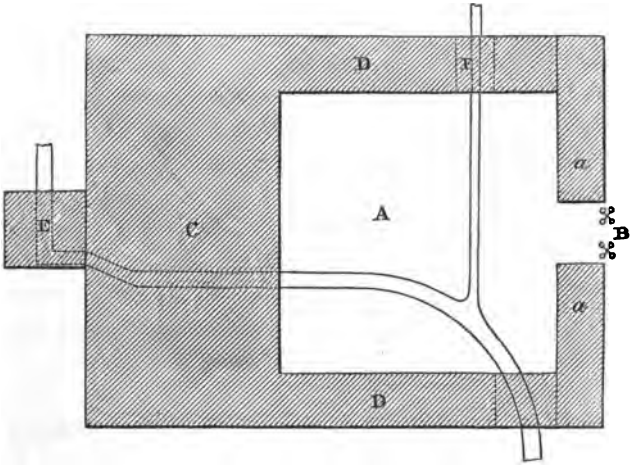
WOOLLEN MILLS.

THE difference between cotton and sheep's wool is that the one is a vegetable and the other an animal substance, and the latter being dissimilar in its characteristic properties, requires a different treatment in the manufacturing processes. The nature of the fibres of sheep's wool, which curl and hook into each other, is different to most other fibrous substances; some of the early preparatory stages in its manufacture into cloth, however, are the same as in that of cotton wool. The peculiar properties of some of the animal wools is their tendency when worked to entwine the fibres, so as to form a species of cloth called felt, without the aid of spinning and weaving. Hats, horsecloths, and other descriptions of clothing, are made in this way, and that by a process called whipping, which separates the fibres by the vibration of a piece of cord or catgut, drawn tight over the extremities of an elastic bow. With this instrument the fibres are separated by a jerking motion of the hand, and fly off in fine flakes into a receptacle ready for use. It is then worked into a sort of pulp, in a vessel of hot water, to the required thickness. The same principle is observed in fulling blankets, broad cloth, and other fabrics of a similar kind; the only difference being that the former is done by hand in a vessel of hot water, and the latter by the stocks or fulling mill. It is to this latter, and subsequent processes where machinery is used, that our attention is chiefly directed; and for that purpose I have selected a woollen mill erected for the Turkish Government at Izmet, on the Gulf of ancient Nicomedia. I might have taken the large establishment of Messrs. B. Gott and Sons, of Leeds, for illustration; but for the same reason of having all the processes on one floor, as in the previous case of the cotton

factory at Bombay, I have deemed it necessary to do the same in that of wool.

There is considerable novelty in the style of the buildings for these works, and the arrangement of the machinery. They were built in 1843, and contained all the improvements of woollen machinery up to that date. They consist of a quadrangular square with a court A, fig. 303, in the centre; B, the entrance; and the buildings on each side, at *a a*, contain the offices and rooms for the Sultan, who took great interest in the works, and frequently visited them. The main building, C, was appro-

Fig. 303.



priated to the machinery; and the side wings, DD, formed the magazines, cloth-rooms, and other conveniencies. E, the water-wheel, in a separate building, gave motion to the machinery in every part of the works. At the end of the wing-buildings on each side were the steam boilers and retorts for gas, and the designs were so arranged as to lock up the whole of the works with one key.

The buildings were erected close to the waterfall, on the side of a steep bank, and were designed for the purpose of having the whole of the operations on one floor and within sight. It was arched with iron, and lighted from the top on the

bazaar principle, a system of building prevalent for ages in the East. The exterior walls were substantially built of stone, with a portico and ornamental entrance, B, in front. It was originally intended to have constructed another water-wheel, as at F; this was not, however, carried into effect.

Plate XVII. is a longitudinal section of the building, showing the piers for supporting the floor, the water-wheel, the machinery of transmission, the dye-house, the position of the machinery, roof, &c.

Plate XVIII. is a plan of the woollen mill, showing the arrangement of the different lines of shafting and the machinery, the different passages between the machines, the water-wheel, &c.

It will be seen from Plate XVII. that the floor of the woollen mill is supported by piers of brick, and resting upon these are the cast-iron columns 20 feet long and 8 in diameter, for the support of the roof. The boiler for the dye-works, which also serves as an heating apparatus, is 7 feet diameter and 24 feet long, and from it cast-iron piping 6 inches in diameter ascends to the woollen mill above.

As the machinery for driving the stocks and gigs is underneath the floor of the woollen mill, it could not well be shown in Plate XVIII. I have therefore constructed an enlarged view, fig. 304, which clearly shows the position of the shafting, and the description of machinery they have to drive.

Water-wheel and Millwork.—Near the city of Izmet a river of considerable dimensions cascades from a height of 28 feet into the gulf, and on the banks of this stream, in the immediate vicinity of the sea, the mill was erected. The water-wheel is on the suspension principle, and, together with the millwork, was manufactured, and the buildings erected, by Messrs. W. Fairbairn and Sons, Manchester. It is entirely of iron, 30 feet diameter and 13 feet wide, with 72 buckets, 1 foot 6 inches deep, and an opening of 7 inches for the entrance of the water into the bucket. The internal segment, *a*, fig. 304, 28 feet 2½ inches diameter, 324 cogs, 3¼-inch pitch, and 14 inches wide on the cog, drives the pinion, *b*, 5 feet diameter, and gives motion to a strong cross shaft and bevel

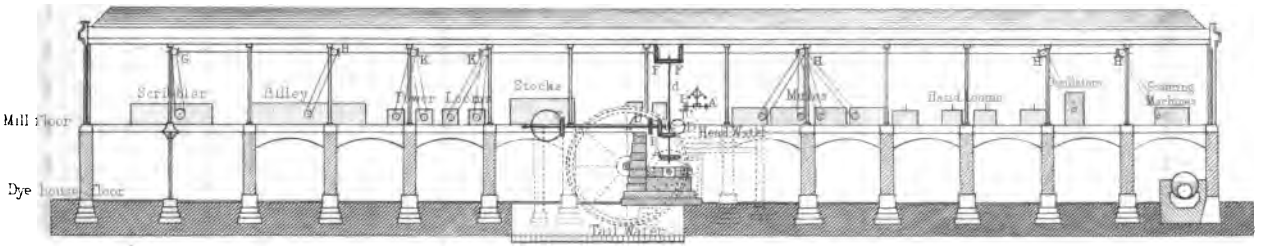
WOOLLEN MILL,

FOR

HIS HIGHNESS THE SULTAN,

ERECTED AT IZMET,

by William Fairbairn & Sons, Manchester.



H. Adlard. sc

London: Longman & Co

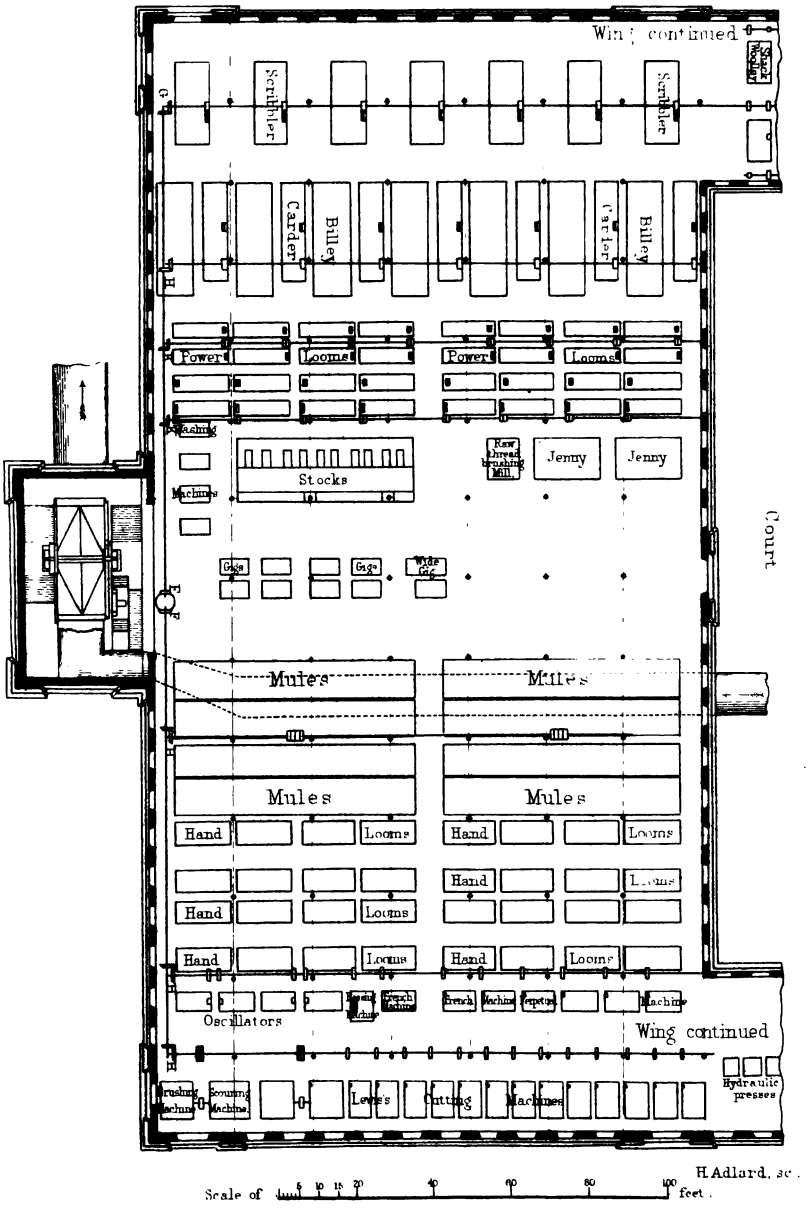
WOOLLEN MILL,

FOR

HIS HIGHNESS THE SULTAN,

Erected in 1843.

by William Fairbairn & Sons, Manchester.

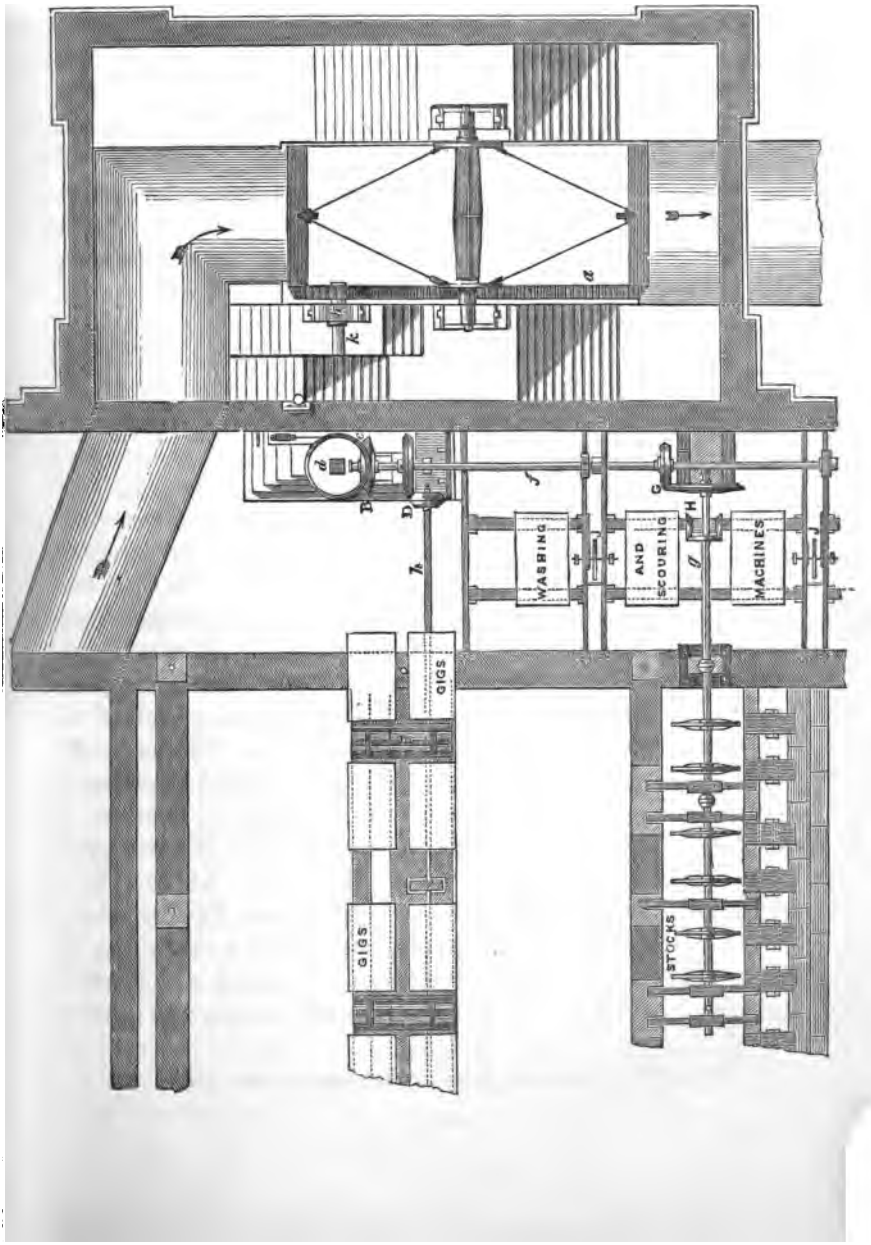


London: Longman & Co

wheel, *c*, from which the motion is conveyed to the mill by the vertical shaft *d*, and the shaft *f*, driving the gig and stock shafts *h* and *g*.

From this arrangement of the first motion wheels, it will be

Fig. 304.



seen (see also Plate XVII.) that the motive power comes almost direct upon the heaviest portion of the machinery, such as the stocks and gig machines, and by the vertical shaft, *d*, and the horizontal and cross shafts above, it is transmitted to the lighter descriptions of machinery in other parts of the mill. The lower portion of the cast-iron vertical shaft is 11 inches diameter; but after giving off the necessary power by bevel wheels to the horizontal shaft for the stocks, gigs, and scouring machines, it is reduced to 10 inches, and tapers to 8 inches at the top. The shafts, *f*, *g*, *h* and *k*, fig. 304, are of cast iron; *f* is 7½ inches diameter, *g* 8 inches diameter, *h* 5½ inches diameter, and the shaft *k* 12 inches diameter. The main horizontal shafts, Plate XVIII., are 4½ inches diameter, and taper to 4 inches at their extreme ends. A plan of the position of the stocks, gigs, and washing and scouring machines, is shown in fig. 304.

The processes pursued in a woollen mill are:

1. Sorting and washing.
2. Teasing and opening.
3. Carding, roving, and spinning.
4. Warping, dressing, and weaving.*

By these different stages of manufacture the wool is converted into cloth. The after-processes may be described very briefly as follows:—After a somewhat similar preparatory process of carding, roving, and spinning, similar to that described under the article cotton, it is taken as it comes from the loom, and submitted to careful washing, by running it over reels through a cistern of water. From this it is transferred to the stocks or fulling mill, and is there submitted to the action of the stock by constant pounding with soap and water in covered boxes, till it attains the required consistency of thickness according to the quality or degree of fineness of the cloth. After this process it is again washed with pure water before it passes to the gigs. Here it is subjected to a severe and almost reverse process; the stocks, by a constant rolling of the cloth in the circular box, give it a thickening or felting character, by the contraction and twisting of the fibres. But the gigs effect a process of separation by teasles (the prickly

* For further information respecting the processes, see Appendix A.

husk or pod of the plant known by botanists as *Dipsacus fullorum*) fixed in a frame attached to the circumference of a cylinder about 3 feet 9 inches in diameter, run at a velocity sufficient to draw out the fibres, and lay them parallel with the line of the cloth. This it will be observed is the very reverse of the previous process, and by a system of teasle carding, the cloth is now prepared, when dry, ready for the sheering or Lewis frame.

The old process of shearing was effected by stretching the cloth in a frame of convenient length, supported by cushions. On the top of the cloth were fixed two large blades or knives worked by power, which, acting as a pair of scissors, clipped off the projecting fibres, and gave what is called a nap or smooth surface to the body of the cloth.

This operation has, however, been superseded by the Lewis frame, invented by Mr. Lewis about the beginning of the present century. This machine consists of an iron frame with fixed rollers, over which the cloth is drawn, and in its passage a roller with a series of thin steel blades or spiral cutters revolves at great velocity, and cuts off the outstanding fibres, previously drawn into position in line with the cloth by the gig machine. This is an expeditious as well as an accurate process, and the cloth sheared in this manner presents, when finished, a close, a shining, and a smooth texture.

After the shearing the cloth is transferred to the brushing machines, where it undergoes a similar treatment in the dry, as it received from the gig machines in the wet state; it is then well brushed and finished ready for the market.

I have endeavoured in this short description of the different processes to give some idea of the manufacture of woollens, as the whole of the machinery in former times was constructed by the millwright. Now it is in the hands of the machine maker, and, like every other manufacturing operation of modern times, the division of labour, and the organisation of separate trades, warrant the extended use of machinery for despatch in the manufacture, and thus insure greatly increased economy, and much greater perfection in the quality of the cloth produced.

It will be noticed that the manufacture of woollen cloths, such as broadcloths, flannels, blankets, &c., is chiefly derived from the short wools. There is, however, a considerable difference

between the woollen and the worsted fabrics, consisting chiefly in the woollen yarn being very slightly twisted, so as to leave the fibres at liberty for the process of felting, whilst the worsted yarn is made from long wool, hard spun, and formed into much stronger thread. The worsted manufacture, and all the mixed fabrics of wool, cotton, flax, and silk, are made by a different process to that of woollen cloth. In the former, the wool, mohair, or alpaca, is cleaned and washed similar to the shorter wool. It is then combed, formerly by hand combs, with rows of long teeth, but now by machines of different constructions, some of them of the circular form heated by steam, and others with the teeth of the combs in line. In combing, a little sprinkling of oil is necessary, in the proportion of a fiftieth or a sixtieth of the weight of the wool, in order to increase the pliancy and ductility of the filaments, and to straighten them in parallel layers as they are drawn from the teeth of the comb, and formed into a roving or sliver. From the combing machine the slivers go to the drawing and roving; and from thence to the spinning machines, in every respect similar to the throstles or water-frames used for cotton. In some cases, and for some description of wools, carding is substituted for combing, and the usual subsequent processes of drawing, roving, &c., are gone through, as in many other operations where the wool travels from its raw state to that of yarn.

In both the woollen and the worsted manufactures the processes are probably more complex than those of most other textile fabrics, and in that of power weaving the difficulties to be encountered have been considerable, owing to the softness of the material and want of twist, or hardness in the yarn forming both weft and warp. From this cause, the power-loom has made slower progress in the woollen manufacture than in that of worsted and all kinds of mixed stuffs, where a stronger yarn and more rigid material has to be dealt with.

The woollen and worsted trades, like most other manufactures, have increased in an accelerated ratio from the commencement of this century up to the present time. We have no reliable returns of the state of the manufacture at the beginning of the present century; but in 1857, according to the factory returns, there were 806 woollen and 445 worsted mills at work, and the total value of the exports of woollen and worsted goods and yarn was 13,645,175*l.*, or about one-fifth of that of cotton.

Description of Gearing		Driver Diameter	Driver Revolutions	Driven Diameter	Result Revolutions per Minute
		ft. in.			
Segments	a	28 $2\frac{1}{2}$	2·2	5 0	12·8 revolutions of main cross shaft.
Wheels, bevel	A	9 8	12·8	4 10	25·6 „ upright shaft.
Wheels, mitre	B	5 3	25·6	5 3	25·6 „ main cross shaft for driving gigs and stock shaft.
Wheels, bevel	C	3 $9\frac{1}{4}$	25·6	7 0	14 „ stocks shaft.
Wheels „	D	6 0	25·6	3 0	51·2 „ gigs shaft.
Wheels, spur	E	4 $0\frac{1}{2}$	51·2	1 $10\frac{1}{2}$	108 „ gigs.
Wheels, bevel	F	6 0	25·6	3 0	51·2 „ cross shaft overhead for driving longitudinal shafts.
Wheels „	G	3 $8\frac{3}{4}$	51·2	2 $0\frac{1}{2}$	92 „ longitudinal shafts over scribblers.
Wheels „	H, H, H	3 6	51·2	1 $10\frac{3}{8}$	92 „ longitudinal shafts over mules, billeys, and carders, &c.
Wheels „	I	3 0	14	1 6	28 „ cross shaft to washing machines.
Wheels, spur	J	4 $8\frac{1}{2}$	28	2 4	56 „ washing and scouring machines.
Wheels, mitre	K K	2 4	51·2	2 4	51·2 „ longitudinal shafts over power-looms.
Pulley	A′	0 $9\frac{3}{4}$	92	2 $0\frac{3}{4}$	36 revolutions of governors.
Worm	B′	0 4	36	1 1	1·2 „ short shaft through the mill.
Wheel	C′	1 6	1·2	1 6	1·2 „ upright shaft.
Worm	D′	0 $6\frac{1}{2}$	1·2	2 $0\frac{3}{4}$	·031 „ rack shaft.
		List of Pulleys and Speeds of Machines.			
14 Pulleys		1 $10\frac{1}{4}$ × 7	92	2 0	85 revolutions of scribblers, two pulleys for each scribbler.
14 „		1 $10\frac{1}{4}$ × 7	92	2 0	85 „ carders „ „ carder.
1 „		1 $11\frac{1}{2}$ × 16	92	1 $9\frac{1}{2}$	100 „ teaser hook woolley.
2 „		2 6 × 9	92	1 $6\frac{1}{2}$	153 „ counter shaft over the shack woolleys.
2 „		2 4 × 14	153	1 2	306 shack woolleys.
8 „		1 7 × 13	92	0 $11\frac{1}{2}$	152 „ mules.
4 „		1 $11\frac{1}{2}$ × 12	92		oscillators.
1 „		2 6 × 12	92		cross rassing machine.
4 „		2 $2\frac{1}{2}$ × 9	92	2 6	80 „ brushing mills.
7 „		2 $5\frac{1}{2}$ × $4\frac{1}{4}$	92	0 7	400 „ French machines and perpetual machines.
15 „		2 $5\frac{1}{2}$ × 4	92	0 5	540 „ Lewis cutting machines.
32 „		1 $3\frac{1}{4}$ × 10	51·2	1 5	46 „ looms or number of picks per minute.

CHAPTER V.

FLAX MILLS.

FLAX MILLS are contemporary with those for the manufacture of cotton and wool, and, in fact, it may be said, that this and almost every other branch of industry received its impetus from the introduction of the steam engine and the improved machinery of Arkwright, which speedily found its way with certain modifications to the manufacture of other textile fabrics besides cotton. Messrs. Marshall and the late Matthew Murray, machine makers of Leeds, are entitled to the merit of having been the first to introduce machinery for the spinning of flax; and the mills of Messrs. Marshall have been in operation since the close of the last century to the present time. Belfast and the linen districts of the north of Ireland were for many years supplied with linen yarn almost exclusively from Leeds, and nothing was done by the Irish manufacturers in the shape of spinning their own flax until 1824, when the first mill was built by Messrs. Mulholland of Belfast. Since that time flax mills have increased to an extent which rivals if it does not exceed the manufacture of Leeds.

The eastern districts of Scotland, Fifeshire, and Dundee, were early in the field, and even as far north as Aberdeen the manufacture of flax has been in a flourishing state. The Scotch flax specimens are, however, chiefly employed in the sail cloth and shirting manufacture, and the facilities afforded for the import of flax from Russia and the Baltic are powerful inducements for the extension of the manufacture in that part of the united kingdom. They also spin, as well as the Irish, considerable quantities of home-grown flax, and the mills in both countries give employment to an active and industrious population.

Mr. I. G. Marshall states in a paper read before the British Association for the Advancement of Science, "That the first

essay in flax spinning in Leeds was made at a small mill driven by water, called Scotland mill, about four miles from Leeds, by my late father, John Marshall, in partnership with Samuel Fenton of Leeds, and Ralph Dearlove of Knaresborough. This was in 1788 and 1789.

"The wonderful success and large profits attending the introduction of Arkwright's invention into cotton spinning had about this time attracted general attention to mechanical improvements applied to manufacturing purposes. The spinning of flax by machinery was a thing much wished for by linen manufacturers. It attracted the attention, amongst others, of Mr. Marshall, who was so strongly impressed with the advantageous field for invention and enterprise offered by flax spinning, that he devoted himself entirely to the new enterprise.

"It appears that some attempts at flax spinning had already been made on a small scale at Darlington, and some other places, as the first spinning machines used at Scotland mill were on a patent plan of Kendrew and Co. of Darlington. This did not answer; experiments were made, and a patent taken out for a plan of Matthew Murray's, then foreman of mechanics with Mr. Marshall.

"In 1791, a mill was built in Holbeck, Leeds, and at first driven by one of Savery's steam engines, in combination with a water-wheel; but in 1792, one of Boulton and Watt's steam engines of 28-horse power was put down. In 1793 there were 900 spinning spindles at work. We may take this small item as our first statical datum of flax spinning in Leeds."

Dr. Ure, in his "Philosophy of Manufactures," speaking of flax, states that "flax is the bark or fibrous covering of the stem of the well-known plant called by botanists *linum*, because it constitutes the material of linen cloth. The spinning filaments are separated from the parenchymatous matter either by steeping the plant in water, or by exposing it for some time to the action of the air and weather. The former, which is the commonest or safest method, is called water retting; the latter is called dew retting.* Both act by a slight degree of fermentation in the

* Since Dr. Ure's work was written new chemical processes have been adopted for separating the bark or husk from the flaxy fibre, by which a great saving of time is effected, the new process occupying only a few days, whereas six weeks were required by the old steeping process.

substance which attaches the flaxy filaments to the vegetable vessels and membranes. The crude flax is dried by being spread on the grass, and is then subjected to an instrument called the brake, which breaks and separates the boon or core from the true textile flax."

As considerable interest is attached to the retting process, so as to cause the bark or straw to separate freely from the filaments, it is necessary to ascertain that the retting is perfect and well dried, after which they are exposed to the action of the double breaking machine, and to this and subsequent processes where machinery comes into requisition I shall more exclusively confine my attention.

To illustrate this subject, I might have selected the large mills of Messrs. Marshall, with whose works I have been professionally connected for a number of years, but as these extensive works do not weave the yarn into cloth, and as some of the machinery is in mills five stories high, and the new mills are under brick arches lighted from the top, it was found more convenient to select a smaller establishment, where the whole of the processes are carried on, from the flax as it comes from the grower till it issues from the mill in the shape of cloth. To attain these objects I have chosen a mill erected some years since at Narva, in Russia, for the Baron Stieglitz, the description of which is as follows:—

Fig. 305 is a longitudinal section, showing the water wheel, the machinery of transmission, the brick arching for rendering the building fireproof, the pillars for supporting the floors, roof, &c.

Fig. 306 is a plan showing the form of the building, the entrance, arrangements of the power-looms, heating apparatus, &c.

The mill was built on the side of a steep bank, and a system of arching, not shown in the drawing, was found necessary for the purpose of levelling the surface. On the piers of these arches, the cast-iron pillars for the support of the iron beams and arches were placed, and over the water wheel is a strong wrought-iron girder, which supports two of the columns and the arched floors above, rendering the whole structure perfectly fireproof. On reference to the plan, fig. 306, it will be seen that

the building is rectangular, with a wing A′ at one end. A bleach house is attached to the end of the mill next the water wheel, and a shaft running parallel to the wall BB′, fig. 306, connected by a cross shaft extending the whole length of the bleach house, gives motion to the machinery of that part by a pair of bevel wheels through the opening B′. These wheels are marked K and L in the list of wheels and speeds. The lower, or first floor, contains the looms for weaving. On the second floor, fig. 305, the preparatory process is carried on, and the top or third floor is exclusively employed for spinning. The heating apparatus consists of a boiler, 5 feet diameter and 12 feet long, from which cast-iron piping 6 inches diameter ascends to the various rooms. The mill is lighted with gas by piping from another mill near at hand, belonging to the same company. The roof consists of wrought-iron principals, to which red deal planking $1\frac{1}{2}$ inch thick, stretching from one principal to the other, is securely bolted. This planking was covered with wrought-iron sheet-plating over the entire roof, as in general use in St. Petersburg and Moscow.

During the building of the mill, it was, however, determined to carry the walls 6 feet higher than they are shown in fig. 305, and by this elevation a large room, 223 feet long and 71 feet wide, was attained, without pillars, for reeling through its entire length. At C′, fig. 306, is the entrance; and over the staircase a water cistern, 40 feet long by 12 feet wide and 6 feet deep, was placed in the attic story for supplying the frames with water and for various other conveniences of the mill.

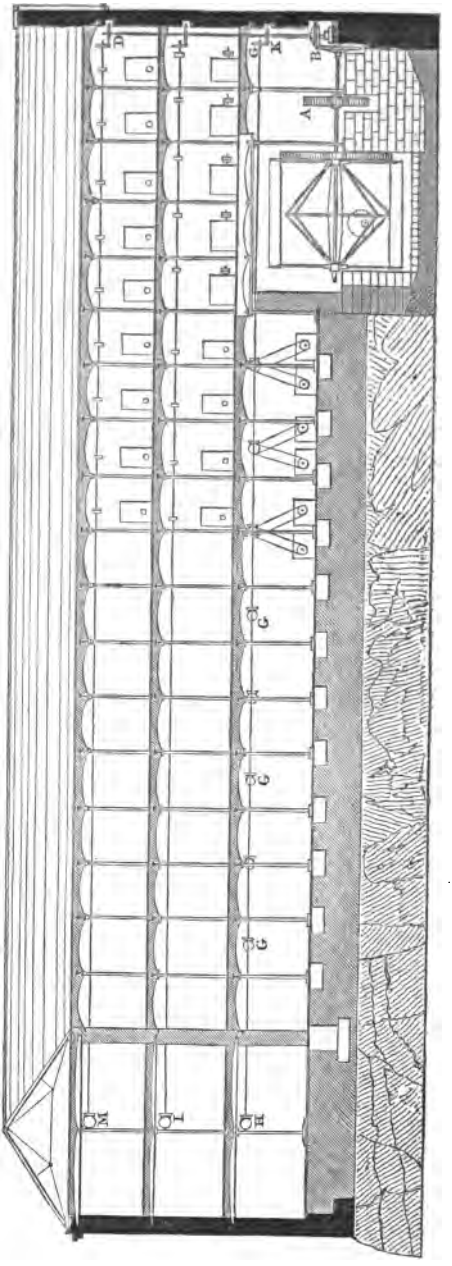
The motive power consists of a water wheel with ventilated buckets, 24 feet diameter and 20 feet wide. It contains 56 buckets, with an opening of $7\frac{3}{4}$ inches between them for the entrance of the water. The internal segments are 20 feet $4\frac{3}{8}$ inches in diameter, with 192 cogs, 4-inch pitch, and 14 inches wide on the cog. Into this wheel the pinion A, 4 feet $6\frac{3}{4}$ inches diameter, with 43 cogs, gears. On the pinion shaft a wheel, 12 feet 1 inch diameter, is keyed, to give motion to a second pinion 4 feet $6\frac{3}{4}$ inches diameter, which is keyed on the shaft for driving the upright at an accelerated speed; and on this shaft the bevel wheel A, which drives the upright,

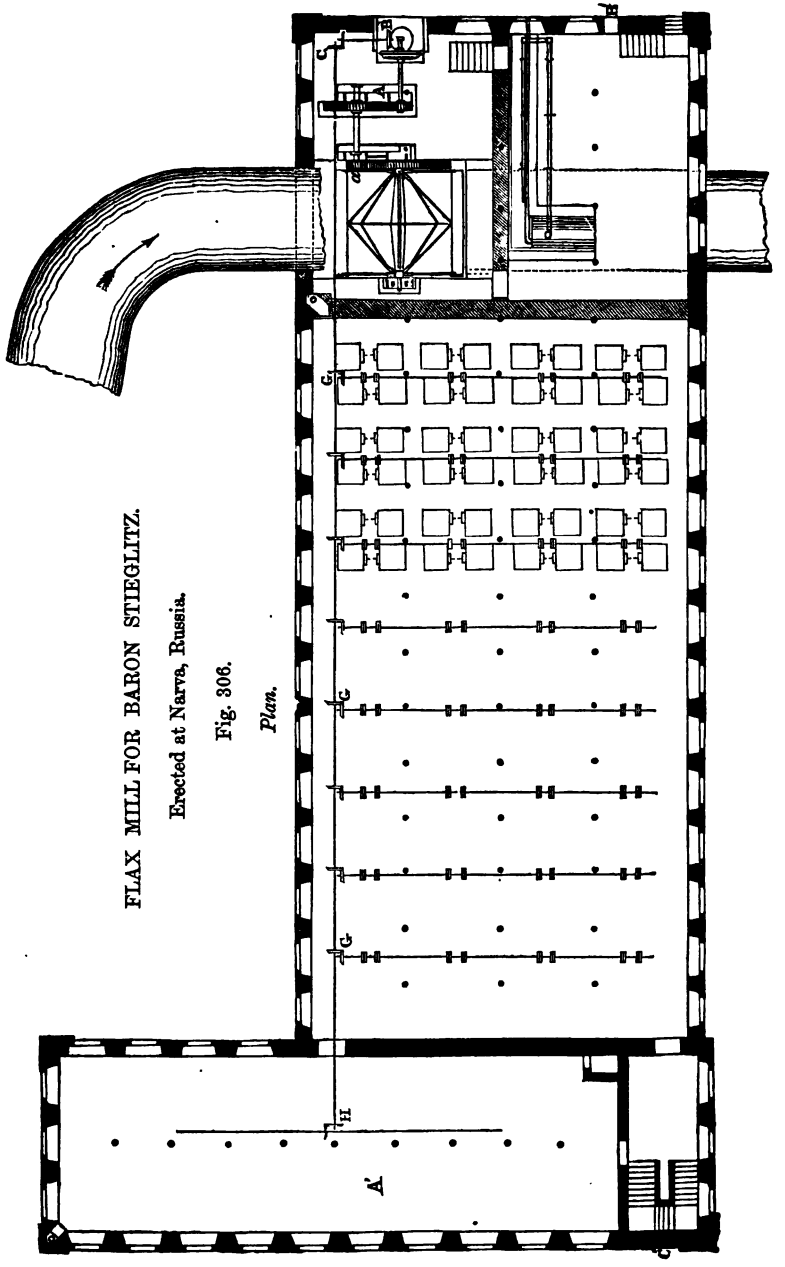
FLAX MILL FOR BARON STIEGLITZ,

Erected at Narva, Russia.

Fig. 305.

Longitudinal Section.





FLAX MILL FOR BARON STIEGLITZ.

Erected at Narva, Russia.

Fig. 306.

Plan.

is also keyed. By reference to the list of wheels and speeds, pages 210 and 211, the form and dimensions of the other wheels will be found, The vertical shaft B is 8¼ inches diameter, and tapers to 6½ inches. The main horizontal shaft over the looms and in the preparing room are 3½ inches diameter, and taper to 2¾ inches at the end. In the third, or spinning-room, the main horizontal shaft is 3¼ inches diameter, and tapers to 2¼ inches at the extreme end. The minor cross shafts are of the same description as those in cotton mills, already noticed at pages 179 and 180, and therefore need no further description.

The Process.—Preparatory to the flax being scutched it is passed over a machine called a breaker. This machine consists of several coarsely-fluted rollers of cast iron, which are heavily weighted, and as the flax is passed through between them, the straw or boon, which has become quite brittle by the process of retting, is broken and partly separated from the fibres of flax. The stricks, or handfuls of flax, are now passed on to the scutching machines, to have the broken straw separated from the fibre. This is effected by causing a series of rapidly-revolving blades or beaters to come in contact with the pendent stricks of flax; and by repeated blows to clear off the straw and give a softness to the flax fibre. There is necessarily a portion of fibre carried off by these beaters. This is afterwards taken out from amongst the shives or broken straws, and is partly cleaned. It is called the scutching tow, and is spun into yarns of the coarsest quality. The scutched flax is now made up into bundles, or, as they are called, heads of flax, and in this state sold to the manufacturer.

As the roots and top parts of the flax are of a quality inferior to the middle portion, it is sometimes found advantageous to cut the flax into three lengths: this is generally done with the finest description of flax from Courtrai and Flanders. The machine used for this purpose is a breaking machine, consisting of four pair of grooved rollers and a rapidly-revolving plate about 20 inches diameter, with a number of projecting diamond-shaped steel cutters on its outer circumference. These cutters occupy a space of about 1½ inch in width. The workman takes a strick of flax, and places it so that it will meet the

cutter at the exact place where he wishes the strick to be broken, and allows the ends to pass on each side between pairs of grooved rollers, which slowly revolve. These carry forward the flax and hold it firmly, whilst the revolving plate with the cutters gradually breaks through the whole of the fibres, and the strick is severed in two. The same process breaks off the outer end. These machines are generally made double with four pairs of grooved rollers, i. e. two pairs on each side of the revolving cutters, so that two men can be employed on the same machine at the same time.

The flax, whether divided or in its full length, must now pass in succession through the various processes of heckling, spreading, drawing, roving, and spinning.

I may here describe an important difference between the state in which the raw material flax is presented to the spinner and that in which cotton, wool, or silk is found previous to being manufactured. The fibres of cotton, wool, and silk are supplied by nature already in their finest state of subdivision; they require merely to be straightened and formed into a continuous thread. In raw flax, on the other hand, the ultimate fibres, which are very fine, are united by a gummy matter into broad strips or ribands, and a very operose process called heckling is required to subdivide the material into finer fibres before the spinning process can begin.

Heckling, the first of these processes, consists in effectually completing the process commenced in scutching, and in splitting the fibres so as to make them equal in size, and also capable of being spun to as fine numbers as possible. Heckling machines are various, according to the quality of the flax to be operated upon; a description of one machine, however, will suffice to show the manner in which the process is carried out: take for example Baxter's Street Heckling Machine for Long Line, and it will be found that this machine consists generally of six gradations of heckles (although that number may be increased if required), fastened upon a strong leather sheet 8 feet wide, each heckle being 16 inches long. This sheet runs at a quick speed over two rollers, and inclines downwards from the part where the heckles first strike the flax. The flax is divided into stricks or handfuls, and being spread into holders is

there firmly compressed by bolts, a little more than one-half of the whole length of fibre being allowed to hang from the bottom bite of the holder. The holder with the pendent strick of flax is now introduced into the head of the machine, which is movable up and down, and by a self-acting motion the holder is pushed forward so as to arrive exactly over the first tool or set of heckles when the head is at the highest; consequently, the heckles commence operating upon the ends of the flax at first, and gradually enter deeper into the strick as the head descends. When the head has attained its lowest point, the bite of the holder is quite close upon the points of the heckle-pins. The head dwells in this position for a short time, to give the flax a proper amount of heckling, and then rises again to the top, pushing the holders forward to the next tool, then turning them round so as to present the other side of the flax to the pins. The same thing is repeated to each holder, until it has passed over the whole of the six tools. It will be understood that each tool contains heckles finer and closer set than its predecessors, so that the action upon the flax is very gradual, and that there is at all times a strick of flax upon each tool, so that there is one delivered at each rise of the head. When the holder and flax is delivered from the machine, the heckled portion of the flax, which, it will be observed, is little more than half, is spread into a holder and fastened as before; the other end is liberated from the holder, and is in its turn subjected to the process of heckling. The short, loose, and weakest fibres, which are taken out by the heckle teeth, are called *tow*, which is also spun into yarn, but of a quality inferior to that produced from line or heckled flax.

The first machine over which the heckled flax or line is passed, is the spreader or first drawing frame, the object of which is to transform the stricks into an endless riband or sliver.

The stricks of "line" are subdivided by the attendant into still smaller portions, of an equal weight, and laid upon a travelling sheet, each small portion being slightly elongated by the hands, and laid so as to overlap about three-fourths of the length of that which was spread before it, it being desirable in spreading to have as equal a thickness over the whole sheet as possible. This travelling sheet carries forward the flax to a pair of rollers

called retaining rollers, which revolve at the same surface speed as the feed sheet. At a distance (regulated by the length of the fibre) from the retaining rollers are another pair of rollers called drawing rollers, and the intervening space is filled with iron bars or fallers, on which are fastened a series of gills or heckles. These fallers rise up close in front of the retaining rollers, and the pins of the heckles enter into the flax as it is passed through by these rollers, and carry it forward to the drawing rollers, the speed of the fallers being calculated to take the flax exactly as it is delivered by the retaining rollers. The drawing rollers revolve at a surface speed, varying according to the material, from 20 to 60 times that of the retaining rollers and gill bars. The flax is consequently drawn out by these rollers to a length from 20 to 60 times what it was when originally laid upon the sheet.

A spreader is generally composed of two feed sheets, and to each sheet there are two gills; there are therefore four slivers formed on the machine at one time, all of which, by means of a condensing plate with four diagonal holes placed in front of the drawing roller, are doubled into one, and passed through a delivering roller into a can. Each can is calculated to hold a certain length of sliver, and the ringing of a bell, connected with the delivery roller, informs the attendant when that length has been delivered.

Next comes the drawing frame. A certain number of cans as they come from the spreader are taken, weighed, and formed into sets of 12, 16, or 24 per set, as the case may be, the heavy and the light cans being arranged so that the total weight of each set is the same. The slivers from these cans are then conducted, 4 or 6 together, between a pair of retaining rollers as in the spreader, drawn by drawing rollers through gills, in the same manner, and all the slivers of the set are again doubled and delivered into one can. The draught between the retaining and drawing rollers is not, however, so great in the drawing frames as in the spreader, varying only (according to the material) from 8 to 24. The process of drawing and doubling is again repeated until the sliver is of an equal thickness in all its parts, care having been taken to regulate the draught of the machines, so that the number of yards of sliver in one pound is suitable for the size of the yarn to be spun.

The roving frame is the next machine over which the sliver is passed. The process of elongating the sliver in this machine is the same as in the drawing frames, but instead of its being doubled after passing the drawing rollers, each sliver is slightly twisted by a flyer, and laid upon a wooden bobbin. Most roving frames are now made self-regulating, in the same manner as those used in the cotton manufacture, the only difference being that for most kinds of flax the bobbins are larger than for cotton. The line is now prepared ready for the spinning frame.

The tow or short fibres thrown out by the heckling machines has also to undergo a process of preparation but slightly different from that to which the line is subjected.

The first operation consists of cleaning and straightening the tangled fibres by means of a carding engine. This machine is composed of a large cylinder 4 or 5 feet in diameter, and 6 or 8 feet in width, the whole of its circumference being covered with teeth set closely together, projecting about $\frac{3}{8}$ths of an inch, and slightly inclined in the direction in which the cylinder turns. The cylinder revolves at about 150 or 200 revolutions per minute, and is surrounded by several rollers, also covered with pins, which assist in straightening and equalising the tow. The first of these rollers are the feeders, a pair of rollers about $2\frac{1}{2}$ inches diameter, which, being fed from a creeping sheet (similar to that employed in the spreader), pass the tow slowly to the cylinder, but, having their teeth set at an angle so as to retain the tow, the cylinder can only take a small portion at a time. After the feeders come several pairs of rollers, 6 or 7 inches diameter, called workers and strippers. The workers revolve slowly with the cylinder, but with their teeth set at a keen angle, and pointing so as to take the material that does not lie straight upon the cylinder. The worker is then cleared by the stripper, which revolves much more rapidly, but not so fast as the cylinder, which in its turn clears the stripper. The tow is thus passed on through several pairs of workers and strippers, each succeeding pair being set closer to the cylinder and to each other until it arrives at the doffers, which are the last of the rollers upon the card. A card has generally 2 or 3 doffers, the last being, of course, set closer to the cylinder than the first; these cylinders

are about 14 inches diameter, and have the teeth bent in the same manner, and revolve in the same direction as the workers. The tow is stripped from the doffers by the rapid strokes of a knife, which rises and falls close to the pins on the face of the roller, and the fibres are conducted and delivered by rollers in the form of a continuous sliver. As it is generally necessary to pass the tow over two cards, the slivers from the first card are formed by a lapping machine into a ball about 20 inches diameter, and from this fed to a second card, which is called the finisher. The construction of the finisher card is the same as the first or breaker card, but the pins are finer and set still more closely. There is also attached to the front of the most improved finisher cards a drawing head, in which all the slivers are drawn over a rotary or porcupine gill, doubled over a plate, and delivered into one can.

The cans from the finisher card are now arranged into sets, and the slivers are doubled, drawn, and made into rove in the same manner as line.

The most important machine that has been for some years introduced into the flax trade, is that known as Flishmann's Tow-Combing Machine, similar to that used in the manufacture of cotton. By passing tows over this machine, they are cleared from all impurities, as well as from the little buttons and knots formed both in heckling and carding, and thus nothing is left but clear fibre. Yarns can be spun from the tow to the same fineness, and having as good an appearance as the yarns produced from the heckled line. As yet, tow-combing is only carried on by a few of the most advanced houses in the trade, but there is every probability that in a few years it will become much more general. Each of the various kinds of combing machines now in use for wool, and several designed expressly for the purpose, have been tried on tows.

The great desiderata in each case are:—

1. The thorough cleaning of the tows from all buttons, shives, &c.

2. The attainment of the above object with the smallest possible amount of loss in waste.

3. The passing of as much weight of material as possible per day.

The machine which has been most successful in obtaining the first-mentioned results, is that known as Flishmann's.

Spinning.—There are three modes of spinning flax; viz., dry, with cold water, and with hot water. Dry spun yarns are chiefly of the coarsest quality, and are used in the manufacture of sail cloth, canvas, sacking, &c. Cold water spun yarns are used principally for shoe threads, and for making twines. The processes of dry and cold water spinning are identical, except that in the latter the fibres as they pass from the drawing roller are damped, which gives the yarn a smoother and more regular appearance. The finest qualities of yarn are the hot-water spun. In this process the rove, before it reaches the retaining rollers to be drawn out, is completely saturated by passing through a trough containing water heated by steam. The hot water macerates the fibres, and dissolves a portion of the gummy matter contained in the flax, and so renders it capable of being spun to a much greater degree of fineness. The length of the fibre is, by this process, very materially shortened, the distance between the retaining and drawing rollers being only from 3 to 4 inches, whilst for the dry spun yarns, the distance is about 18 inches for line, and 8 or 9 inches for tow. The strength of the yarn is not, however, at all impaired by this, and it is much smoother and more even than that spun in the full length.

Reeling, the next operation, is the winding of the yarn from the bobbins round a barrel $2\frac{1}{2}$ yards in circumference. 120 revolutions of this barrel make a lea, or 300 yards, which the attendant ties up separately,—10 leas constitute a hank, and 20 hanks a bundle. It is in bundles that the yarn is generally made up, and a small machine called a 'Bundling Press' is used to compress the yarn into as small a space as possible, previous to its being sent to market.

The above description of the flax process has been kindly furnished by Messrs. Fairbairn and Co. of Leeds, to whom and the late Sir Peter Fairbairn the flax trade is greatly indebted for the introduction and working out of the screw gill and other preparatory machinery.

It will not be necessary to enter into the process of weaving, as the power-loom has made slow progress in the manufacture of linens, which are chiefly woven on the hand-loom. For the coarser descriptions of cloths the power-loom has been adopted, but not successfully in fine linen, as there appears to be great difficulty in dressing and preparing the warps, and I believe at the present time most of the Irish linens are manufactured by the hand-loom weavers of Ulster.

In Manchester and other parts of the manufacturing districts, a description of mixed goods called domestics are manufactured for shirtings, and are wove on the power-loom the same as cotton. The late firm of Messrs. Leys, Mason, and Co. of Aberdeen, were at one time large manufacturers of the coarser linens by power, and several attempts at linen power-loom weaving have been made in other establishments, but not successfully, either as regards fine linens or cambrics. Most of the flax mills in Leeds confine their operations to spinning, with the exception of Messrs. Marshall, who of late years have paid considerable attention to weaving by power, I believe successfully, but the difficulties have not been altogether surmounted, and several years may yet elapse before this important desideratum in the manufacture of flax into cloth is attained. Much has already been done, but the results so far have not been attended with complete success, and can therefore only be looked upon as experimental.

The bleaching, beetling, polishing, and finishing of linen are carried on extensively in the North of Ireland, and at Barnsley, in Yorkshire. It is an important branch of industry in both countries, and, to effect these objects, machinery for boiling in lea, washing, drying, calendering, winding, packing, pressing, &c., is requisite. In some descriptions of goods the beetling process is adopted, and this consists in winding the cloth on to an iron cylinder of about 20 inches diameter, placed under a row of stampers 4 inches square, made of beech, which by a revolving tappet-shaft raises the stampers and allows them to fall in succession upon the cloth, until it attains a beautiful polish and wave-like appearance.

Annexed is a list of wheels and speeds, and the number and size of the pulleys, with the velocity of the different machines.

List of Wheels and Speeds.

Water-wheel, 24 feet diameter. Velocity on periphery = 4·4 feet per second = 3·5 revolutions per minute.

Description of Gearing	Driver		Driven	Result
	Diameter	Revolutions	Diameter	Revolutions per Minute
	ft. in.		ft. in.	
Segments . . . a	20 $4\frac{3}{8}$	3·5	4 $6\frac{3}{4}$	15·6 revolutions of cross shaft.
Wheels . . . . A	12 1	15·6	4 $6\frac{3}{4}$	41·1 ,, shaft driving upright.
Wheels . . . . B	7 $11\frac{3}{4}$	41	3 $11\frac{3}{4}$	82·3 ,, upright shaft.
Mitre wheels . . CC	3 2	82	3 2	82 ,, cross shaft No. 1.
Bevel ,, . . DD	4 0	82	2 $2\frac{3}{8}$	149 ,, cross shaft in Nos. 2 and 3 room, preparing and spinning-rooms.
Mitre ,, . . EE	2 5	149	2 5	149 ,, longitudinal shaft in No. 2 preparing-room.
Mortice bevel wheels FF	3 $5\frac{5}{8}$	149	2 1	248 ,, ,, shafts in No. 3 spinning-room.
Mitre wheels . . G	3 2	82	3 2	82 ,, ,, shaft in No. 1 weaving-room.
Bevel wheel . . GGGG	2 2	82	2 0	88 ,, cross shafts in No. 1 weaving-room.
Mitre ,, . . H	2 4	82	2 4	82 ,, cross shaft in wing building, No. 1 room.
Mitre ,, . . I	2 4	149	2 4	149 ,, shaft in wing No. 2 preparing-room.
Mitre ,, . . J	1 8	88	1 8	88 ,, cross shaft, No. 1 winding-room.
Bevel ,, . . K	2 3	82	2 $0\frac{1}{8}$	90 ,, cross shaft to bleach-house.
Mitre ,, . . L	2 0	90	2 0	90 ,, shafts in bleach-house.
Bevel ,, . . M	1 $1\frac{1}{2}$	248	2 3	124 ,, cross shaft, No. 3 wing, mechanics' shop.
Governor Speeds.				
Pulley . . . . A′	0 $9\frac{1}{4}$	82	1 9	36 revolutions of governors.
Spur wheel . . B′	0 8	36	2 0	12 ,, cross shafts.
Spur ,, . . C′	0 5	12	1 9	2·8 ,, shaft across cistern.
Bevel ,, . . D′	1 $1\frac{1}{2}$	2·8	2 3	1·4 ,, worm shaft.
Worm ,, . . E′	0 $6\frac{1}{2}$	1·4	2 $0\frac{3}{4}$	0·38 ,, rack shaft.

List of Pulleys and Speeds of Machines.

Number of Pulleys	Driver			Driven	Result
	Diameter	Width	Revolutions	Diameter	Revolutions per Minute
	ft. in.	ft. in.		ft. in.	
32 Pulleys	1 5	1 2	88	1 2	106 revolutions of heavy looms.
8 ,,	1 6	1 2	88	1 2	113 ,, light looms.
8 ,,	1 5	1 2	88	1 4	93 ,, light looms.
2 ,,	2 1	0 8½	88	1 10	100 ,, pumps.
2 ,,	1 10	0 7	88	1 11	84 ,, calender.
1 ,,	1 0½	0 10	88	1 6	60 ,, cauderoy.
2 ,,	1 0½	0 10	149	0 10	200 ,, shaft-winding.
4 ,,	1 5¼	0 9	149	1 4	160 ,, warping-machine.
4 ,,	1 8	0 8	149	1 4	180 ,, dressing-machine.
2 ,,	1 10½	0 8½	149	1 6	180 ,, spreader.
5 ,,	2 2½	0 9	149	1 8	200 ,, finisher-card.
1 ,,	1 10¼	0 7	149	1 6	180 ,, line 1 drawing.
2 ,,	2 0	0 9	149	1 6	200 ,, line 2 drawing.
1 ,,	2 3	0 7	149	1 6	225 ,, line 3 drawing.
6 ,,	1 5½	0 9	149	1 2	180 ,, tow-drawing.
2 ,,	1 6½	0 8	149	1 6	150 ,, roving.
1 ,,	2 0	0 9	149	1 6	200 ,, roving.
2 ,,	1 10½	0 7	149	1 6	180 ,, tow-roving.
3 ,,	2 2½	0 9	149	1 8	200 ,, break card.
1 ,,	1 8	0 8	149	1 4	180 ,, break card.
1 ,,	2 0	0 9	149	1 6	200 ,, teaser.
1 ,,	0 10	0 10	149	1 8	120 ,, lap.
2 ,,	1 3¼	0 6	149	1 2	160 ,, heckling.

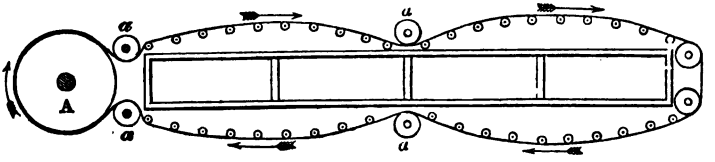
CHAPTER VI.

SILK MILLS.

Dr. Ure, in his "Philosophy of Manufactures," states, "that the silk-worm is a precious insect, which was first rendered serviceable to man in China, about 2,700 years before the Christian era. From that country, the art of rearing it passed into India and Persia. It was only at the beginning of the sixteenth century that two monks brought some eggs of the silk-worm to Constantinople, and promulgated some information on the growth of the caterpillars. This knowledge became, under the Emperor Justinian, productive of a new source of wealth to the European nations. From Greece, it spread into Sicily and Italy, but did not reach France till after the reign of Charles VIII., when the white mulberry-tree and a few silk-worms were introduced into Dauphine by some noblemen on their return from the conquest of Naples. No considerable result took place till, in 1564, Traucat, a common gardener of Nismes, laid the first foundation of a nursery of white mulberry-trees, with such success as to enable them to be propagated within a few years over all the southern provinces of France." The cultivation of the mulberry, according to this statement, dates from an early period, but the silk manufacture, like most other branches of industry, was first introduced into this country by emigrants from France and Italy, during the persecution of the Protestants, and shortly before the Edict of Nantes. At that time, everything was done by hand, from the cocoon to the web, as it left the hands of the weaver. The winding, throwing, spinning and weaving, were all effected by manual labour, until the first silk mill, driven by power, was introduced by Mr. John Lombe into Derby, about the year 1716. For a series of years this mill and others, constructed from the same model, did nearly the whole of the spinning, and the throwsters, as well as the hand spinners, were, in consequence, superseded by the greater economy, accuracy, and despatch of the new manu-

facture. The neighbourhoods of Spitalfields, Coventry, and Macclesfield, became the chief seats of the silk manufacture, and for a considerable time they continued to enjoy the monopoly without little, if any, change or improvement in the machinery. The trade seemed to languish rather than improve until after the peace of 1815, when it was introduced on a greatly increased scale into Manchester, where it underwent the same changes and improvements as most others of the textile fabrics. The machines for spinning, doubling, and throwing silk continued for nearly a century the same as they were when first introduced into Derby. They consisted of a wooden frame, about 3 feet 6 inches wide and 7 feet high, with two or three tiers of spindles, each tier being driven by an upright shaft A and large drums, with tightening pulleys, as shown at *a*, *a*, &c., fig. 307.

Fig. 307.



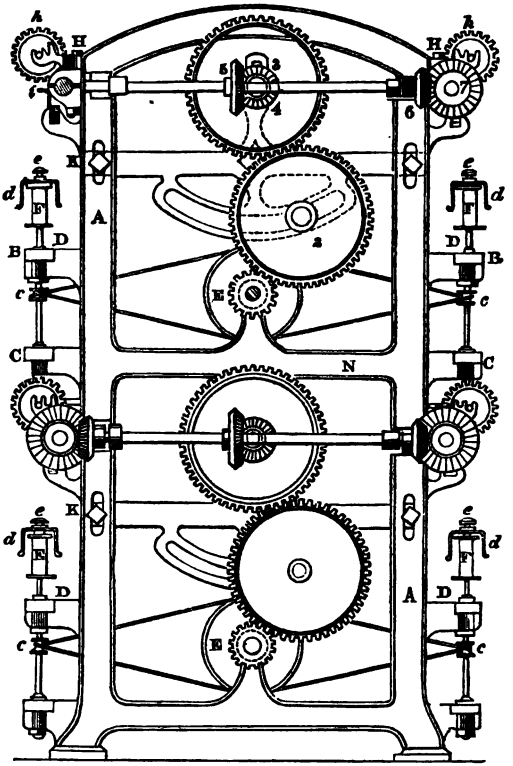
Leather straps passed round the drums, and pressing upon the wharves of the spindles, carried them round on the same principle as the 'wiper' or the spinning of a wheel caused to revolve round its axis by a tangential force applied to its circumference. This mode of driving continued in operation for a great number of years without variation, until the late Mr. Vernon Royle built a large silk mill in Manchester, when the whole of the machinery underwent a total change, wooden frames and friction traps were removed, light cast-iron frames and cotton bands were substituted for driving the spindles, and the whole machine was remodelled on the same principle as the throstle for spinning cotton. These improvements were introduced by the late firm of Fairbairn and Lillie, and the result was a great improvement in the motion of the spindles and a great increase of speed, by which one-half more yarn per spindle was produced than what could be obtained from the old frames. The alterations were further improved by the late Mr. Ritson and

Messrs. Wren and Hopkinson, to whom I am indebted for the description of the present improved process in the manufacture, and to whom silk manufacturers may be referred as the best makers of this description of machinery.

The following section of the improved machine is taken from Dr. Ure's work on the 'Philosophy of Manufactures:'—

"The machine for twisting the single threads of silk, either before the doubling or after doubling, is called the spinning-mill, sometimes also the throwing-mill, though the latter term

Fig. 308.



End view of Fairbairn and Lillie's Improved Silk Spinning-mill.

often includes all the departments of a silk mill. The section of this apparatus in fig. 308 shows four equal working lines, namely, two on each side of the frame, one tier being over the other. In some spinning-mills there are three tiers, but the

uppermost is a little troublesome to manage, as it requires the attendant to mount a stool or steps.

"A A are the end frames or uprights, bound with cross-bars N N; and two or more similar uprights are placed immediately between the ends. They are all connected at their sides by beams B and C, which extend through the whole length of the machine. D D are the spindles, having their top bearings fixed in the bar B, and the bottom or step bearings in the bar C. These two bars together are called by the workmen the spindle-box: *c c* are the wharves, turned by cords passing from the horizontal tin cylinders E, which lie along the middle of the mill, midway between the ranges of spindles. F F are the bobbins with the double silk, which are fixed on the tapering spindles by pressing them down; *d d* are little flyers, or forked arms of wire attached to a disc of wood or washer, which revolves loosely upon the top of the said bobbins F F and round the spindles, one of their arms being sometimes bent upwards to serve as a guide to the thread; *e e* are pieces of wood pressed on the top of the spindles, to prevent the flyers from being thrown off; *h h* are the ends of the winding bobbin-shaft, laid in slots near H, as in the former machines. The winding bobbins are driven by toothed wheels cast on one end of their square iron axes, in the line of *h*, which wheels are turned by toothed wheels on a bar in the line of the bevel wheel 7. On these bobbins, fig. 309, which are of considerable diameter, the silk is wound, and distributed

Fig. 309.

Bobbins of spirally wound silk.

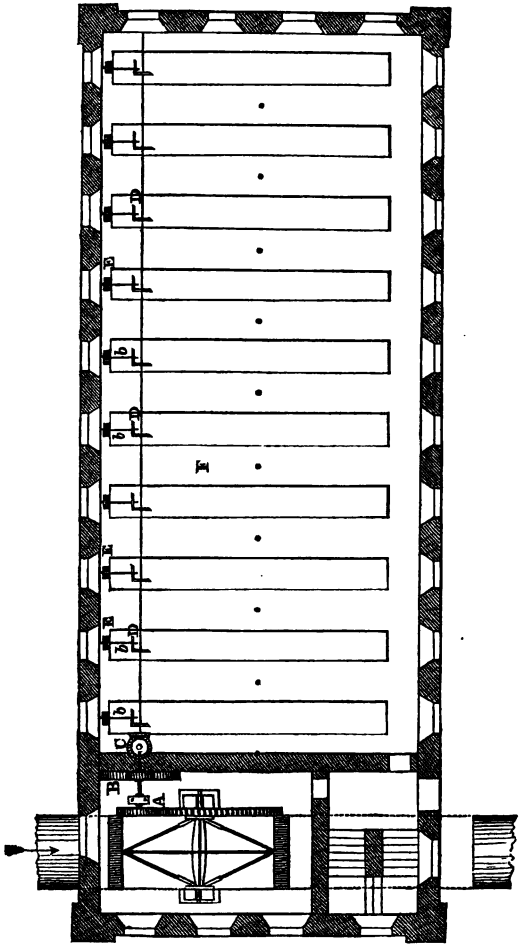
diagonally by a peculiar differential mechanism. K K are the guide bars, with the guides *i*, through which the silk passes, being pulled by the winding bobbins on their horizontal in the line of *h*, and delivered by the flyers *d d*, from their vertical twisting bobbins and spindles F. By the revolution of the tin cylinder E, driven by a steam-pulley fixed on its end, motion is communicated immediately through the cords to the wharves *c*,

and their spindles; and mediately through the plate-wheels 2 and 3, and the bevel-wheels 4, 5, 6, 7, to the rest of the machine. The toothed wheel at E is called the change-pinion, because, by changing it for another of a smaller or a larger size, the speed of the plate-wheel 2 and 3 may be changed. The axis of the plate-wheel 2 lies in a curvilinear slot, in which it can be shifted to suit the size of the change-wheel put in at E, and to keep it in proper gearing, after which it is fixed by a screw-nut."

We have selected for illustration a silk mill erected some years since in the south of England, driven by a water-wheel 22 feet diameter and 10 feet wide inside the bucket. The internal segments are 20 feet 6 inches diameter, $2\frac{1}{2}$ inches pitch and 8 inches wide on the cog. The segments communicate motion to a spur wheel 4 feet diameter, and by the shaft A, fig. 310, on which a second spur wheel is keyed, the motion is conveyed to the line of horizontal shafting on the ground floor, and also to a line of vertical shafts which communicates with the rooms above. The bottom room F, figs. 310 and 311, is filled with spinning frames, and driven by the small cross shafts *b*, *b*, *b*, &c.; the second floor, C, fig. 311, is occupied by doubling machines and throwsters, and the upper floor H contains the lighter description of machinery, and is chiefly employed in preparing the hanks for the throwing and spinning and winding the yarn as it comes from the machines below.

The building consists of three stories and an attic, at one end of which is the water-wheel and staircase, and the adjoining buildings contain the boiler for heating, gas works, &c. &c. For some years this mill was worked exclusively by water, but subsequently it was found necessary to have steam as an auxiliary, and hence followed a considerable extension of the mills, and a corresponding increase of machines.

Fig. 310.



The following references and calculations exhibit the speed of the water-wheel and the shafting, spinning frames, &c., in the mill :—

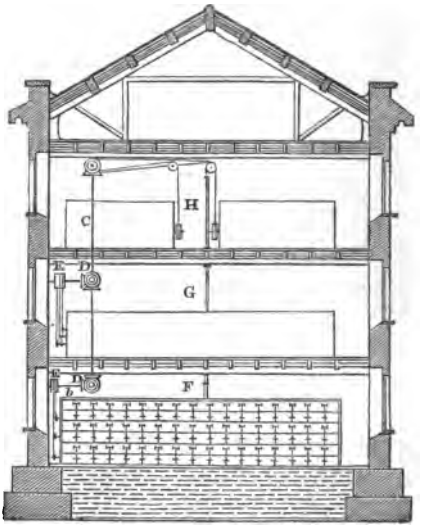
SPEEDS OF SHAFTS, WHEELS, &c.

Water-wheel, 22 feet diameter; velocity of periphery, 4 feet 2½ inches per second, = 3·7 revolutions per minute.

Description of Gearing	Driver		Driven	Result
	Diameter	Revolutions	Diameter	Revolutions per Minute
Spur segments A	20 6	3·7	4 0	18·96 revolutions of cross shaft
Spur wheels B	9 0	18·96	3 1	55·17 revolutions of horizontal shaft
Bevel wheels C	3 9	55·17	2 6	62·75 revolutions of upright shaft
Bevel wheels D D D, &c.	1 10½	55·80	1 1	96·53 revolutions of cross shafts
Pulleys on shaft do.	2 6	96·53	0 8	361·98 revolutions of frames.

The speeds of the throwsters, &c., in the second room are the same as the spinning on the ground floor, and the winding machines are driven slow to suit the quality of the silk as it is drawn from the hanks.

Fig. 311.



The *Raw Silk Spinning Machinery* is used for the winding and twisting of silk as imported into this country in hanks: the thread being already formed in the cocoon, no drawing process, as in cotton, is needed, and the skill of the manufacturer is exercised in freeing the imported hanks from knots, lumps, and entanglement, "sizing" or matching the strands of silk and spinning them together, so that the twist shall be regular and perfect, and for this purpose the machines in general use are usually named winding, cleaning, spinning, throwing, dyed-silk pirn-winding, &c.

The hanks being of different lengths, two sizes of winding machines are used—one suitable for hanks imported from China and Persia, and about 120 inches long, and the other for Indian and Italian, about 72 inches long; but the principle of action being alike in both, one description will suffice. The hank is extended on a swift, which is constructed of wood, being a small centre with metal pivots, with slender arms of lancewood radiating in pairs from this centre; each pair of arms has a string tied round them, so that the hank is distended into a hoop, or rather hexagon, which readily revolves and unwinds; the bobbin which takes up the silk from the swift lays horizontally, and is rotated by friction-rollers, so that when through entanglement or otherwise the swift ceases to revolve and give off the thread of silk, these rollers slip, and the bobbin stops without breaking the thread, when the attendant can adjust the work and remove the impediment to motion. Sometimes this winding is done upon a machine which also cleans the silk, but usually there is a separate machine for this purpose, where the bobbin from the winding frame is placed on a shelf near the floor, and from it the thread is unwound and rewound upon a bobbin on a spindle on the top of the frame; this spindle is in the same position and rotated by friction rollers precisely as in the winding frame, but the silk in its way from one bobbin to the other is passed through a cleaner, which is two knives of steel, of which the edges are set parallel to each other, and a minute distance apart; according to the fineness of the silk so is this distance made more or less by means of adjusting screws, and the object of this is to remove from the surface of the silk thread all knots or other excrescences which may interfere with the regularity

of twisting, and of the woven goods. Sometimes this cleaning is produced by passing the silk thread between two steel rollers about $\frac{5}{8}$ of an inch diameter, also adjustable by screws, with the same object of arresting knots and lumps, until the attendant removes them from the thread. After the silk has undergone the process of cleaning it is ready for the spinning machine, which twists the single thread so as to give it strength and increased elasticity for the manufacture of sewing silks and the warps of woven fabrics, and this is a machine similar to that described at page 213, consisting of two or three tiers of upright spindles rotated by a tin roller turning them by cotton banding, or in some machines by an endless leather belt revolving horizontally round the machine, and rubbing against each spindle in its circuit; on these upright spindles the bobbins of silk from the cleaning machine are placed, so as, whilst each spindle is rapidly rotated, the thread is being drawn off, and again wound upon another spindle placed horizontally, and turned by small toothed gear, or by friction rollers. These machines have the usual arrangements of change pinions to suit the required twist per inch in the thread, and it is of the highest importance that the delivery and taking up of the thread shall be uniform, otherwise the defective and irregular twist will seriously deteriorate the beauty and value of the manufactured fabrics. This machine fulfils in the economy of the silk manufacture the function of the throstle or the mule in the cotton trade, and sometimes the spinning, together with the processes of doubling and throwing, is done at one operation, as in Shute's patent, where the larger spindle carries round with it two or more smaller bobbins upon spindles, which being revolved in a contrary direction, by rubbing against a stationary band, spin, double, and throw upon one machine. Other varieties of machines have been adopted for the same end, but on account of the diminished speed of the spindles, increased loss in waste, and greater cost in wages, the plan most commonly adopted is to double and "to throw" on distinct and separate machines. The doubling machine is similar in form to the cleaning machine. The bobbins from the spinning machine are placed upon a shelf near the floor, and the ends of silk from two or more bobbins, according to the sort of work done, are wound together

in one cord or strand on a bobbin rotating horizontally, and moved by friction rollers, as in the winding and cleaning frames; but it is essential that this cord or strand shall in every part of its length be composed of the same numbers of the ends of silk laid evenly, and with the same amount of tension, together. Before the silk arrives at the bobbin on which it is to be wound each fibre or end passes through the eye at the end of a light wire lever, which, whilst all is going on properly, is upheld by it, but should one of the fibres of silk break, then its wire lever drops upon a second lever, and, overbalancing it, causes its further end to rise up, and arrest, by means of a ratchet-wheel, the motion of the winding-on bobbin: thus, without the stoppage of the machine in general, that particular bobbin waits motionless for the attention of the operative, when the broken end of the fibre is re-pieced, and, the levers being restored to position, the silk proceeds as before. After the silk has thus been doubled, or several threads lain evenly together, it is taken to the throwing machine to be again twisted, for the doubling machine does not, as in the cotton manufacture, double and twist at one time; and this twisting, as in cotton, is effected by the spindle revolving in a contrary direction to that of the spinning machine. This process is almost a repetition of the spinning, except that, in place of winding on to bobbins, this is done upon reels of 43 to 44 inches circumference; indeed, many silk throwsters throw their silk upon the spinning machine by placing the spindle bands so as to rotate the spindles in the contrary direction, and then reel off the silk into hanks ready for the dyer. The silk when dyed is re-wound from the hank upon bobbins of tin or wood, by machines named soft or dyed-silk winding-frames, similar in principle and action to the winding machines for raw silk, and the bobbins are now delivered to the weaver for warping and winding upon pirns for weft. The warping machines are of the usual form, with a large wooden fly as in cotton warping, and the weft is wound on pirns by girls, with the simple hand wheel (forming one at a time), or in the most modern mills by the pirn winding machine, which contains 40 to 100 spindles, under the care of one attendant: the pirn is formed upon bobbins specially shaped for the purpose, sometimes by running in a metal internal cone, which as

the pirn fills gradually forces it upwards, until its spindle is out of gear from the driving power, and then it remains motionless until the attendant re-adjusts the position of the spindle and places on it an empty bobbin. The same effect is produced by three small conical formed rollers pressing on the outside of the bobbin, but both these varieties of machine have been found to be injurious to the delicate shades of colour in the dyed silk, as by the compression and friction the thread is flattened and glazed, and thus rendered unequal in appearance when in the piece goods; and to obviate this serious defect the plan used by the best manufacturers is to wind the pirn without external pressure upon the bobbin, which is placed on a spindle, which by toothed gear gradually sinks down in the machine, until its driving band arrives at a loose pulley, which then allows the spindle to rest until the full pirn is removed; or by another mode, the traverse or winding-on rail rises gradually, and effects the same object. In this description of the silk manufacture, I have not gone minutely into a description of the mechanical arrangements necessary to produce these beautiful and costly fabrics; in point of fact, the machines are not intricate in construction, but they require careful workmanship. The traverse rods for forming the bobbins are moved by the well-known appliances called the sun and planet crank motion, the simple crank, the heart, the oval wheels, the mangle wheel motion, &c.; and whilst one manufacturer for the peculiarities of his business may adopt one or more of these, another may prefer the application of others to his machines. Many manufacturers in this advanced age of sewing silks, in Leek and elsewhere, spin and throw with the simple hand-wheel, where a boy (as in twine or rope making) carries the ends of silk and makes them fast at the other end of a room, and the man called the twister rapidly whirls the hooks on which the silk is tied, gradually moving up the wheel as the twisting proceeds to accommodate the shortening of the thread; then, after his judgment tells him that the thread is sufficiently twisted, he fastens two or more ends of the twisted silk upon one hook, reverses the direction of revolution in his hand-wheel, and throws all into one strand.

Lately, there have been introduced to the silk trade several

novel machines which, though they have not hitherto ob tained extensive use in this country, may prove useful aids to silk industry. One is a mode of winding the silk from the cocoon, and spinning it on the same machine. This has been done by Mr. Chadwick and others of Manchester, and beautiful work produced, but the difficulties in a new machine of turning off a paying quantity of work, joined to the want of commercial facilities for obtaining from abroad an adequate supply of cocoons, has hitherto impeded the success of the experiment. Another is a mode of "sizing" or measuring the thickness of the silk thread, by passing it between two or more rollers nicely adjusted, and so arranged that when a part of different thickness occurs, the rollers move a system of levers which either stop the winding-on bobbin, or else transfer the thread to another bobbin. This operation is also accomplished by taking paper spools exactly alike in weight, and winding upon each of them a definite number of yards of silk, then with a delicate balance assorting them, placing those of like weight in distinct lots, and thus obtaining a number of spools with equal lengths and weights of silk to be put together on the doubling machine; for this matching is essential to the regularity of the twist in the silk spinning, as when threads of unequal diameters are "thrown" together it is very difficult to prevent its being unevenly done, and harder twisted in one place than another, or "corkscrewed," as it is technically called. At present, it is the office of a manager or operative of approved skill to size or match by the eye or touch the various bobbins of raw silk, before placing them on the spinning or doubling machines. To meet this purpose there has also been invented in France a doubling system which, in place of taking several distinct strands or threads of silk, and winding them together, as in the doubling machine first described, only deals with one thread of silk, which in an ingenious manner is doubled or rather tripled upon itself into three strands, by means of a traversing carriage like that of a cotton mule, putting at the end of each traverse a loop in the silk, doubling, and thus, so to speak, matching the silk with itself, with the same view of attaining an improvement in the manufacture of the thread when twisted together. In the silk dye-house, a very useful machine from America has

recently been introduced. To the present time, the silk, after being dyed, has been "stringed" or glossed by means of the severe hand labour of men twisting it in the hank with sticks to and fro, so as to rub the strands together, and produce the beautiful lustre so characteristic of the material; this required strong and skilful men, and with every exertion a workman could not finish much per day; but the machine in question entirely dispenses with the great physical exertions of the workman, and enables him to produce a larger amount of polished silk. This operation is performed in a box of cast iron with a steam-tight door, in which the silk can be placed on two rollers, the upper one adjustable to suit the varying lengths of the hanks, and the lower roller is fixed upon the head of a piston rod attached to a piston moving downwards in a steam cylinder; when the silk is placed upon the rollers, the door is shut, and the high pressure steam introduced, thoroughly saturating the silk; then by another valve the steam enters the steam cylinder, and the silk, whilst immersed in steam, is strongly stretched by the pressure applied to the piston; during the process, the silk hank is slowly revolved upon the rollers by gearing communicating with the outside of the box, so that the shades of colour shall not be varied at those parts of the hank which bend round the rollers, and a few seconds suffice for the completion of several hanks.

This class of machinery is, with slight modifications, adapted for the manufacture of sewing silks, warp and weft for piece goods, and for crape; but for inferior fabrics in silk the waste or spun silk is used, and this manufacture is very similar to that of flax or fine cotton. The waste silk from the cocoon winding factories or the raw silk manufactories is combed or heckled, then cut into lengths of from $1\frac{1}{2}$ to 5 or 6 inches, then placed in the opening machines, afterwards sewn up in small bags, and boiled, to cleanse it from gum and other impurities, and, after drying, is batted or opened with sticks like fine cotton; from this it is passed through breaker and finisher carding engines, drawing and roving frames, and mules constructed with rollers of spaces and adjustments adequate for fibres of this length, when it is reeled and dyed as the raw silk before described.

The introduction and description of the different preparatory processes in the manufacture of the textile fabrics—although not bearing directly on the subject of millwork, for which these volumes were originally written—are nevertheless analogous, and worked so closely into each other that a treatise on mills and millwork would not have been considered complete unless the processes of manufacture for which the mills were designed were introduced. This must, therefore, be my apology for the introduction of matter which appears to belong more to the machinery of manufactures than to the wheels, shafting, and pulleys by which they are driven.

On the question of what is the province of the millwright, and what exclusively belongs to the machinist, we are yet, notwithstanding the great advances made in the division of labour, unable to state where the millwright ends and the engineer and mechanist begin. There is no correct nor definite line of demarcation between the one or the other; and it is a curious fact that the industrial mechanical progress of the last half century has not marked any reliable principle of organisation by which one mechanical operation is distinguished from another. They seem to run into each other without any definite outline of distinction, and the millwright of the present day appears to maintain as in past times his original character of a "Jack of all trades," and there are none of the varied forms of mechanical manipulation pursued in this country in which the millwright is not employed. This is the state in which he appears to germinate, alternately changing from the mill to the machine, and from the machine to the equally important duties of the civil engineer. We have many instances of these transmigrations in the history of Brindley, Smeaton, and Rennie; and I believe there is no lack of them at the present day, as many examples may be adduced of men who have risen to distinction from the humble origin of a working millwright.

To show the intimacy which exists, and the claims which the millwright has upon almost every mechanical profession, I may instance that of corn mills, in which not only the moving power, whether wind or water, but all the machinery is exclusively devoted to the skill of the millwright; and it is for this

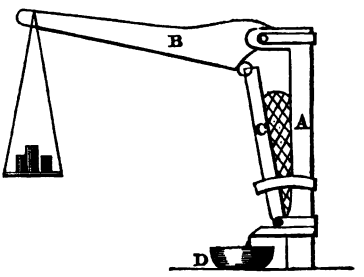
reason that I have endeavoured to describe more minutely the various machines and movements in that department of manufacture than in those of the textile fabrics. In the latter, the trades are divided and subdivided into machine-makers, smiths, fitters, turners, &c., but the millwright stands alone as an operator in all these trades; and although the name may be lost in the changes which have taken place in the organisation of the different callings, there is, nevertheless, a sprinkling of the old trade requisite to give character and consistency to the industrial progress of the country. Having thus described the mills for corn, cotton, and other textile manufactures, I have now to revert to paper mills, oil mills, powder mills, &c., in which the millwright undertakes the construction of the whole or the more prominent parts of the machines of which these establishments consist.

CHAPTER VII.

OIL MILLS.

THE means adopted for extracting oils from seeds and nuts in the early stages of civilisation were of a very primitive kind, consisting simply of a few poles driven into the ground supporting two horizontal cross-bars, between which a bag containing the seed was placed. A lever was then brought to bear against one or both of the horizontal levers, causing severe pressure upon the seed from which the oil was expressed. This rude apparatus, long in use in India and Ceylon, was necessarily slow and inefficient, but an improvement was introduced by

Fig. 312.



Mr. Herbert, whose object was to construct what he considered a powerful and effective machine. It consisted of an upright post A, firmly fixed in the ground, the stump of a tree being frequently used, upon the upper and lower ends of which were fixed levers B and C, the upper one forming the fulcrum of the horizontal lever B, and the lower one the joint of the vertical lever C. At the top of this was fixed a roller to diminish the friction of the lever B. The pressure was obtained by the weight

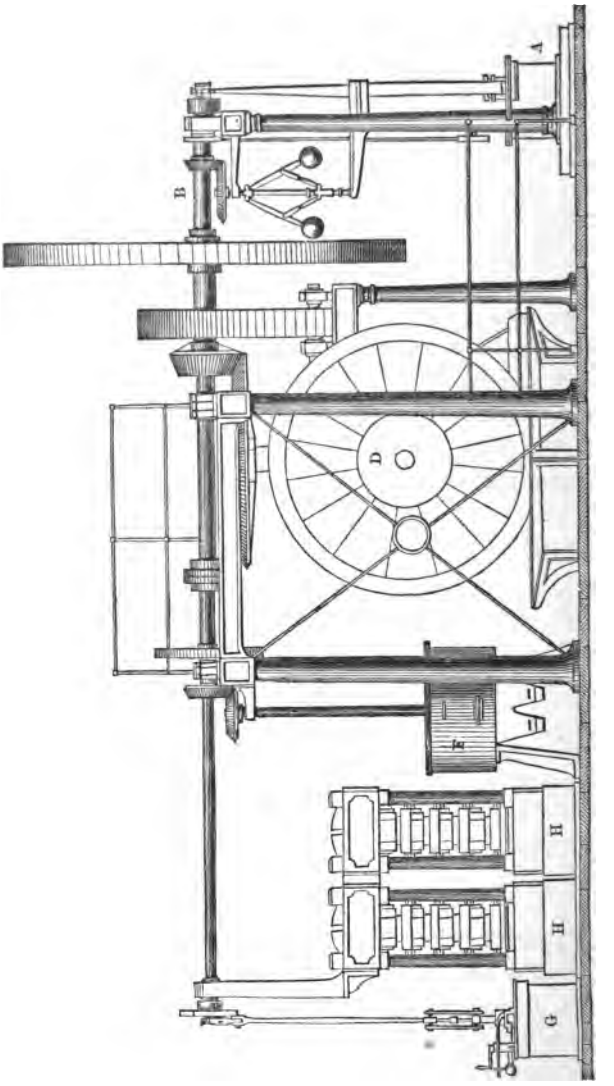


Fig. 313.
ELEVATION.

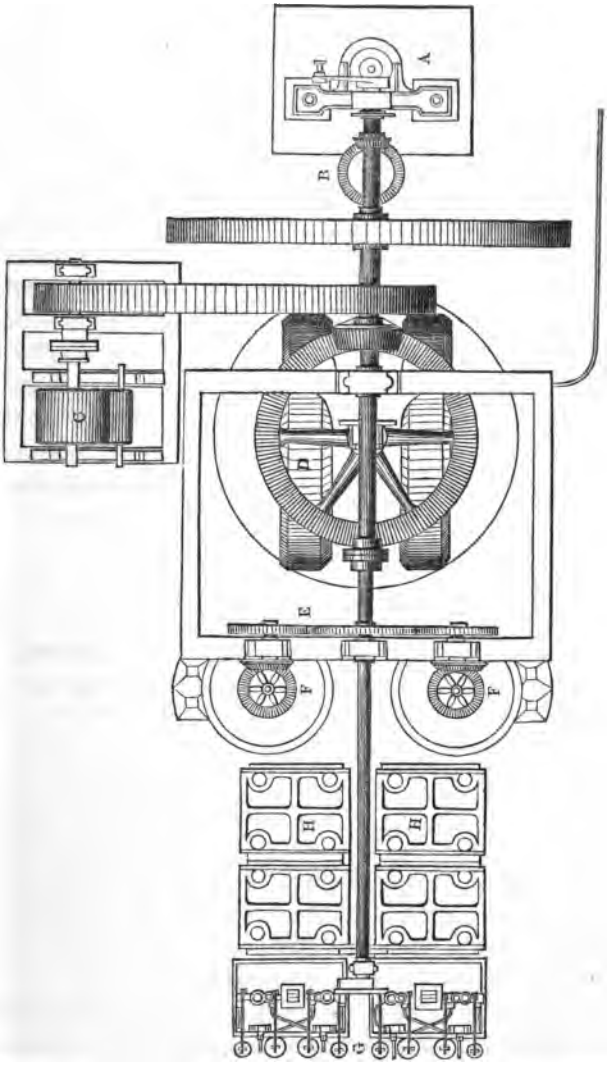


Fig. 314.
PLAN.

of a man applied to the end of the lever B, and that, acting on the vertical lever C, brought it in contact with the bag containing the seed which expressed the oil—on the principle of a pair of nut-crackers—into the vessel D below. Machines of this description with double levers came into use, but all of them were very imperfect, and until the Dutch stamper-press was introduced from Holland, there was no machine in this country entitled to consideration as an oil mill. The screw and the hydraulic press are recent inventions of this country; but, before considering their comparative merits, it will be necessary to refer, generally, to the course of operations to be performed previous to the compression of the seed, which is the last of five operations to which it is subjected, and to which we will refer in order after having described the general arrangement of the mill.

The foregoing is a plan and elevation of an oil mill complete with crushing rollers, edge stones, steam kettles, and hydraulic pumps, as constructed by Messrs. Martin Samuelson and Co., Hull. The compact form of this construction is evident from having the motive power and the machinery of the different processes constructed within a comparatively small space. It moreover renders the operations of crushing, grinding, heating, and extraction continuous, and on this principle a completely finished oil mill may be erected in a single room or shed with no other requirements than the necessary room to facilitate the operations of the mill.

Fig. 313 is an elevation and fig. 314 is a plan of this description of mill, which may be explained as follows:—A is the steam engine giving motion to the horizontal shaft B which drives the crushing rollers C and the edge stones D. By a train of spur gearing E, the stirrers or agitators in the steam pan F receive motion, and the main shaft continued forward works the hydraulic pumps and presses G H.

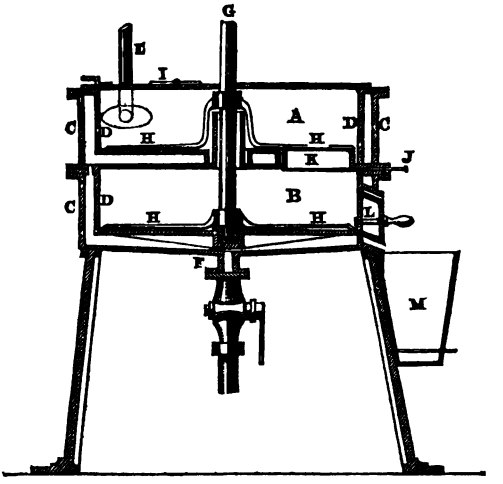
The *first* operation, then, consists in passing the seed through a flat screen or shaker, which is kept in a constant state of agitation to clear it of all foreign matter and to prepare it for the *second*, which is to pass the seed through a pair of crushing rollers. In this operation the two rollers are of unequal diameters the larger one being 4 feet diameter, and the smaller 1 foot diameter, the breadth of both being 16 inches, or 14½ inches on

the face. The larger roller makes 56 revolutions per minute, driving the smaller one by friction. The seed is supplied through a hopper by means of a small roller very slightly grooved, which is made to revolve for the purpose of feeding the main rollers, being driven by a strap from the larger roller passing over a pulley outside the hopper. The amount of feed is regulated by a movable plate adjusted by a screw. Underneath the rollers are placed scrapers kept in contact with them by weights, for the purpose of removing any seed adhering to the surfaces during the process of crushing. These rollers for a long time were made of equal diameters; but is was found that they crushed the seed neither so well nor so expeditiously as they do in their present proportions. After the equal sized rollers were found to be inefficient, that known as the Ipswich mill was adopted, in which the larger roller was 6 feet diameter, and the smaller 1 foot diameter; but experience proved that, when any hard substance got between the rollers, the leverage over the journals was so great that it caused much wear and tear upon those parts. Seed crushers have, therefore, by degrees adopted the medium sized rollers, which are found to be exceedingly effective and not liable to derangement. A pair of rollers, such as described, will crush upon an average about 4½ tons of seed in 11 hours, which is sufficient for two sets of hydraulic presses.

The *third* operation consists in grinding the seed under a pair of edge stones, weighing together about 7 tons, and making about 17 revolutions per minute. The stones, if of good quality, and the seed pure, require to be faced every three years, and will last for a great length of time. One pair of edge stones will grind sufficient seed for two double hydraulic presses; the time of grinding being about 25 minutes, when it is ready for transfer to the *fourth* operation, which is to heat the seed in a double steam kettle of the annexed form, fig. 315, which represents a vertical section. The kettle consists of two cylindrical chambers A and B, one above the other, each of which is composed of an external casing C, which surrounds the interna or inside kettle D, with a sufficient space left between the two round the sides and bottom to allow a free circulation of the steam. The steam is admitted by the pipe E, and the condensed

water passes off at F from the bottom of the kettle. The shaft G gives motion to two arms or stirrers H H, in each chamber, revolving at the rate of 36 revolutions per minute, which keep the seed constantly agitated, so that every particle of it may come in contact with the heated sides and bottom of the kettle. The upper chamber A is covered with a sheet-iron lid I, through which the kettle is charged. In heating the seed, the upper chamber A is filled first, and the seed is allowed to remain in it from 10 to 15 minutes; the slide J is then withdrawn, and the seed falls through the opening K into the lower chamber B, where it remains until it is required to be taken to the press;

Fig. 315.



the door L is then opened, and the whole of the seed is discharged from the chamber B by the action of the revolving stirrers H. The seed falls through a funnel M, under which is placed a bag of suitable dimensions to contain a sufficient quantity of seed to make a cake weighing 8 lbs. after the oil is expressed from it. Each of the chambers in the heating kettle will contain sufficient seed for charging one single press; the heating of the seed is therefore a continuous operation of first charging the upper chamber A, and then allowing the seed to pass into the lower one B, in which it is heated to 170° Fahr., and is then withdrawn and placed in the bags.

The bags after being filled are placed separately between what are called the hairs, which are bags made of horsehair with an external covering of leather. The same description of bags and hairs are used, whether the oil be expressed by means of the stamper, screw, or hydraulic press.

The *last* operation is that of expressing the oil by pressure through the interstices of the bags, and this is done either by a square-threaded screw press, or by stampers which are of Dutch origin. The stamper press consists of a long rectangular box open at the top; at each end there are two plates, between which one bag of seed is placed, yielding a cake of 9 lbs.; next to one of the inner plates is a filling-up piece, then an inverted wedge, then another filling-up piece, after which is introduced a vertical driving-wedge, and, lastly, another filling-up piece is inserted between the driving-wedge and the other inner plate. As soon as the bags have been placed vertically in the press-box, a stamper made of hard wood, about 16 feet long and 8 inches square, with a descent of about 22 inches in the final stroke, is allowed to fall at the rate of 15 strokes per minute for a period of about 6 minutes upon the head of the driving-wedge, which is sufficient to drive it down level with the top of the press-box, the stamper being worked by two cams, or wipers, on a revolving shaft. Side by side with the first stamper is a second one, immediately above the inverted wedge, which is held suspended at a fixed point by means of a lever, while the first stamper is in action; but as soon as it is time to remove the bags, the first stamper is raised by means of a lever above the point at which the cams come in contact with it, and by the same means the other stamper, which was previously suspended, is allowed to fall upon the inverted wedge, driving it downwards and thereby releasing the working wedge, so that the attendant may remove the bags and repeat the operation. A press like this will not do more than 12 cwt. of cake per day.

The last mode of expressing the oil is by means of the hydraulic press, which may fairly be said to be the most approved system that has yet been adopted. This press is simply Bramah's press arranged specially for the purpose of expressing oil, and appears to have been in use for this work

more or less for thirty years, although the earlier presses were very defective as compared with those in use at the present time.

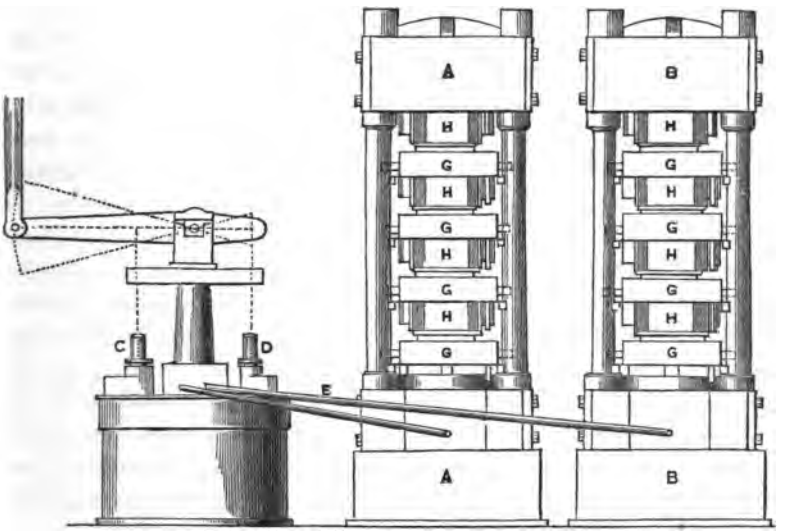
One of the first hydraulic presses applied to oil mills was constructed by Messrs. Martin Samuelson and Co. of Hull, to whom I am indebted for the description of the machinery.

In this arrangement, only one press and one set of small pumps is introduced. The box which receives the seed is in one piece, and runs upon a small tramway for the purpose of withdrawing it from the press to remove the cake and replenish the bags; each time, therefore, that the press is put in operation, the entire box has to be withdrawn, in order to empty and replenish it; it is then replaced upon the ram, after which it is lifted bodily upwards so as to bring it into contact with the press-head, which fits accurately in the press-box, and acts as the point of resistance when the pressure is upon the ram. The constant withdrawal and lifting of this heavy box must evidently be a great loss of power and time. Presses of this description were at work at Deptford for a number of years, but they have recently been removed and replaced by those known as Blundell's presses, which are now universally admitted to be the most efficient appliance for the purpose.

Blundell's double hydraulic press is shown in the annexed cut, fig. 316, which shows a vertical section of the press with an elevation of the pumps. The double hydraulic press consists of two distinct presses A and B, supplied by two pumps C and D, one of which, C, is $2\frac{1}{2}$ inches diameter, and the other, D, 1 inch diameter, both connected to each distinct press cylinder by means of hydraulic tubing E. The stroke of each pump is 5 inches, and they make 36 strokes per minute; the larger pump C is weighted to 740 lbs. per square inch pressure, and the smaller, D, to 5,540 lbs. per square inch. The diameter of the press rams is 12 inches, and the stroke 10 inches. Each press is fitted with four boxes G G, and receives four bags of seed in the spaces H H, producing in all a weight of 64 lbs. of cake at each operation. After the heated seed has been removed from the heating kettle, and placed in the canvas and hair bags, —which is done as speedily as possible, so that it may retain its

heat,—the attendant first fills one press A, and opens the communication between the large pump C and the charged press A, by means of valves, which causes the ram to rise until there is a total pressure of about 40 tons exerted on the press; the safety-valve connected with the large pump C then rises, and is kept open by means of a small spring catch. Whilst this operation is going on in the first press A, the second press B is being filled in the same manner; the communication is then opened between the large pump C and the press B by means of valves; the safety-valve of the pump C having been replaced

Fig. 316.



in its original position, the ram of the second press B is then raised to a corresponding position with that of the first press A, when the safety-valve of the pump C rises a second time. The communication between the large pump C and the press B is then closed, and at the same time a communication is opened by the valves between the small pump D and the presses; and the extreme pressure exerted by the small pump D, amounting to about 300 tons, is allowed to remain upon the rams for about 7 minutes from the time they were first brought into action;

this, together with 3 minutes allowed for emptying and charging the press, is the full time required for expressing the oil in the most effectual manner. The oil in leaving the seed passes through the canvas bag, and then through the hair bag, where it finds a free exit at the edges; thence it runs into a channel or groove, which passes round the upper portion of each press-box G; a communication is made from one box to another by means of piping, so that the oil passes from the upper boxes through the lower ones, and thence into the cistern, which is called the spell-tank, being just large enough to hold the produce of one day's work. These presses are not worked with water; it has been found that oil which is not of a glutinous nature works much better, and keeps both the pumps and presses in a better condition. It is scarcely possible, if the presses are properly constructed, that they should meet with any accident: this can only occur through carelessness, when excessive weight is placed upon the safety-valve levers, and the valves themselves are allowed to stick through want of cleanliness, from the attendant not taking care to remove the oil, which sometimes becomes clotted round the valves. Each press is capable of producing 36 cwt. of cake per day of 11 hours, and the yield of oil may be taken at about 14 cwt. in the same time; this, of course, depends much upon the quality of the seed. The cake is trimmed, or pared at the edges, by means of a small paring knife, after which it is put into a kind of rack to allow it to cool and dry, so that it will not become mouldy when stacked. The oil is pumped from the spell-tanks into larger tanks, capable of holding from 25 to 100 tons, where it is allowed to remain for some time for the purpose of settling, previous to being brought to the market in that condition, or undergoing various other processes, such as refining, &c.

For all practical purposes, the screw press is quite unfit as compared with either the stamper or the hydraulic press, from the objection that it is constantly liable to break-downs when driven by steam-power, there being no portion of the machinery that will yield if the pressure is not relieved in time, either by the attendant or by some self-acting contrivance, the best of which are very uncertain in their action; whereas in the case of

the stamper press, the stamper being loose and independent of the press-box, any risk of breakage by an overstrain or excess of pressure is in a great measure avoided by the stamper recoiling and leaving the wedge at a fixed point after it is tightly driven home.

The following comparative results of the stampers and the hydraulic presses, as exhibited in Messrs. Earles and Carter's oil mills at Liverpool, may be interesting. On the same area of floor, 121 feet by 30 feet, where 12 stampers were previously employed, the largest quantity of seed crushed in one year, working during the day, was 13,000 quarters; but with 8 hydraulic presses, working day and night, they have produced 52,000 quarters; this would be equivalent to about 30,000 quarters for day-work only; and with 10 hydraulic presses, which now form the complement, they will crush 65,000 quarters of seed, working day and night. With the stampers they were compelled to work the seed twice over, whereas with the hydraulic presses it is only necessary to work it once, in both instances yielding the same quantity of oil, and the consequent saving of labour of nearly 25 per cent. The difference in point of wear and tear between the two modes of crushing is also found to be considerable in favour of the hydraulic presses, while the cost of wedges with the stampers is very considerable. Altogether there is an important saving in the new method, either as regards the amount of labour or the power required to work the hydraulic presses.

The practical conclusions to be drawn from the results appear to be that, in the same sized mill, the hydraulic presses produce about three times as much oil as the stampers. They do this with less wear and tear, at a considerable reduction of labour (since the seed has only to be handled once), and the general expenses of working the hydraulic mill as compared with the stampers, owing to the increased production, is much less per quarter of seed crushed in the former than in the latter process. The consumption of coal, general charges, and interest on capital, plant, &c., is the same whether 13,000 quarters per annum are crushed by the stampers, or three times that quantity by the hydraulic presses.

In conclusion, we may observe that it appears, from official

returns in 1841, that the quantity of seed imported into this country for the oil manufacture was 364,000 quarters; in ten years it increased to 630,000 quarters; and in 1856 it was 1,100,000 quarters, producing about 144,000 tons of cake and 56,000 tons of oil.

CHAPTER VIII.

PAPER MILLS.

Dr. Ure, in his "Dictionary of Arts, Manufactures, and Mines," states, in his article Paper, "it is much to be regretted that, in tracing the origin of so curious an art as that of the manufacture of modern paper, any definite conclusion as to the precise time or period of its adoption should hitherto have proved altogether unattainable. The Royal Society of Sciences at Göttingen, in 1755 and 1763, offered considerable premiums for that especial object, but, unfortunately, all researches, however directed, were utterly fruitless. The most ancient manuscript on cotton paper appears to have been written in 1050, while Eustathius, who wrote towards the end of the twelfth century, states that the Egyptian papyrus had gone into disuse but a little before his time."

Speaking of the origin of the manufacture, it may be stated that the Chinese were early in the field, and probably gave birth to the art of making paper from vegetable matter reduced to pulp long before its introduction into Europe. Dr. Ure observes that, "Several kinds of their paper evince the greatest art and ingenuity, and are applied with much advantage to many purposes. One especially, manufactured from the inner bark of the bamboo, is particularly celebrated for affording the clearest and most delicate impressions from copper plates, which are ordinarily termed India proofs. The Chinese, however, make paper of various kinds, some of the bark of trees, especially the mulberry tree and the elm, but chiefly of the bamboo and cotton tree, and occasionally from other substances, such as hemp, wheat, or rice straw. To give an idea of the manner of fabricating paper from these different substances, it will suffice (the process being nearly the same in each) to confine our observations to the method adopted in the

manufacture of paper from the bamboo—a kind of cane or hollow reed, divided by knots, but larger, more elastic, and more durable than any other reed. The whole substance of the bamboo is at times employed by the Chinese in this operation, but the younger stalks are preferred. The canes being first cut into pieces of 4 or 5 feet in length are made into parcels, and thrown into a reservoir of mud and water for about a fortnight, to soften them; they are then taken out and carefully washed, every one of the pieces being again cut into filaments, which are exposed to the rays of the sun to dry and to bleach. After this they are boiled in large kettles, and then reduced to pulp in mortars, by means of a hammer with a long handle; or, as is commonly the case, by submitting the mass to the action of stampers, raised in the usual way by cogs on a revolving axis. The pulp being thus far prepared, a glutinous substance extracted from the shoots of a certain plant is next mixed with it in stated quantities, and upon this mixture chiefly depends the quality of the paper. As soon as this has taken place the whole is again beaten together until it becomes a thick viscous liquor, which, after being reduced to an essential state of consistency, by a farther admixture of water, is then transferred to a large reservoir or vat, having on each side of it a drying stove, in the form of the ridge of a house, that is, consisting of two sloping sides touching at top. These sides are covered externally with an exceedingly smooth coating of stucco, and a flue passes through the brickwork, so as to keep the whole of each side equally and moderately warm. A vat and a stove are placed alternately in the manufactory, so that there are two sides of two different stoves adjacent to each vat. The workman dips his mould, which is sometimes formed merely of bulrushes, cut in narrow strips and mounted in a frame, into the vat, and then raises it out again, the water passing off through the perforations in the bottom, and the pulpy paper-stuff remaining on its surface. The frame of the mould is then removed, and the bottom is pressed against the sides of one of the stoves, so as to make the sheet of paper adhere to its surface, and allow the sieve (as it were) to be withdrawn. The moisture, of course, speedily evaporates by the warmth of the stove, but before the paper is quite dry it is

brushed over on its outer surface with a size made of rice, which also soon dries, and the paper is then stripped off in a finished state, having one surface exquisitely smooth, it being seldom the practice of the Chinese to write or print on both sides of the paper. While all this is taking place the moulder has made a second sheet, and pressed it against the side of the other stove, where it undergoes the operation of sizing and drying precisely as in the former case."

With respect to the time when the manufacture of paper was first introduced into England, we have no reliable data. The earliest trace of a paper mill is supposed to have been erected at Stevenage, in Hertfordshire, about the year 1498 or 1499; also in Scotland, about the middle of the seventeenth century, when a company was formed for the manufacture of white writing and printing paper. But, in fact, little was done in the way of perfecting the manufacture till the middle of the last and the beginning of the present century. Up to the latter period the only machinery then in use was the rag engine, and the moulds and felts as practised by hand in single sheets from the liquid pulp. It is a curious fact that, notwithstanding that paper has been made in this country and other parts of Europe from two to three centuries, few if any improvements, till of late, have been effected in the shape of machinery for the purpose of increasing the quantity and reducing the cost of the manufacture. Such was the imperfect state of the manufacture when a working model of a continuous machine was introduced into this country from France, from the paper manufactory of Monsieur L. Didot, at Essonne. This occurred in 1801, when the invention was purchased by Messrs. Fourdrinier, whose experiments and labour in perfecting the machine were never rewarded. Subsequently it passed into the hands of the late Mr. Donkin, of Bermondsey, of whose improved machine and the drying and cutting machine attached we give a sketch.

During a recent alteration of the paper duties, a long and vigorous opposition was maintained on the part of the manufacturers against the Legislature. It was maintained that the price of rags from the continent would be greatly increased, and that serious injury would be the result. These fears have not, however, been realised, as a number of resources were at hand, and

the variety of substances which enters into the formation of pulp and the manufacture of paper is so great, that I cannot refrain from again quoting Dr. Ure.

The Doctor says that, "Silks, woollens, flax, hemp, and cotton, in all their varied forms, whether as cambric, lace, linen, holland, fustian, corduroy, bagging, canvas, or even as cables, are or can be used in the manufacture of paper of one kind or another. Still, rags, as of necessity they accumulate and are gathered up by those who make it their business to collect them, are very far from answering the purposes of paper-making. Rags to the paper-maker are almost as various in point of quality or distinction as the materials which are sought after through the influence of fashion. Thus the paper-maker, in buying rags, requires to know exactly of what the bulk is composed. If he is a manufacturer of white papers, no matter whether intended for writing or printing, silk or woollen rags would be found altogether useless, inasmuch, as is well known, the bleach will fail to act upon any animal substance whatever. And although he may purchase even a mixture in proper proportions, adapted for the quality he is in the habit of supplying, it is essential, in the processes of preparation, that they shall previously be separated. Cotton in its raw state, as may be readily conceived, requires far less preparation than a strong hempen fabric; and thus, to meet the requirements of the paper-maker, rags are classed under different denominations, as, for instance, besides fines and seconds, there are thirds, which are composed of fustians, corduroy, and familiar fabrics; stamps or prints (as they are termed by the paper-maker), which are coloured rags, and also innumerable foreign rags, distinguished by certain well-known marks, indicating their various peculiarities. It might be mentioned, however, that, although by far the greater portion of the materials employed are such as have already been alluded to, it is not from their possessing any exclusive suitableness—since various fibrous vegetable substances have frequently been used, and are, indeed, still successfully employed—but rather on account of their comparatively trifling value, arising from the limited use to which they are otherwise applicable."

The same authority goes on to state, that "almost every species of tough fibrous vegetable, and even animal substance,

has at one time or another been employed; even the roots of trees, their bark, the bine of hops, the tendrils of the vine, the stalks of the nettle, the common thistle, the stem of the hollyhock, the sugar-cane, cabbage stalks, beet-root, wood shavings, sawdust, hay, straw, willow, and the like. Straw is occasionally used, in connection with other materials, such as linen or cotton rags, and even with considerable advantage, providing the processes of preparation are thoroughly understood. Where such is not the case, and the silica contained in the straw has not been destroyed (by means of a strong alkali) the paper will be invariably found more or less brittle; in some cases so much so as to be hardly applicable to any purpose whatever of practical utility. The waste, however, which the straw undergoes, in addition to a most expensive process of preparation, necessarily precludes its adoption to any great extent. Two inventions have been patented for manufacturing paper entirely from wood. One process consists in first boiling the wood in caustic soda lye, in order to remove the resinous matter, and then washing to remove the alkali; the wood is next treated with chlorine gas or an oxygenous compound of chlorine in a suitable apparatus, and washed to free it from the hydrochloric acid formed; it is now treated with a small quantity of caustic soda, which converts it instantly into pulp, which has only to be washed and bleached, when it will merely require to be beaten for an hour or an hour and a half in the ordinary beating-engine, and made into paper. The other invention is very simple, consisting merely of a wooden box enclosing a grindstone, which has a roughened surface, and against which the blocks of wood are kept in close contact by a lever, a small stream of water being allowed to flow upon the stone as it turns, in order to free it of the pulp, and to assist in carrying it off through an outlet at the bottom. Of course, the pulp thus produced cannot be employed for any but the coarser kinds of paper. For all writing and printing purposes, which, manifestly, are the most important, nothing has yet been discovered to lessen the value of rags, neither is it at all probable that there will, inasmuch as rags, of necessity, must continue accumulating, and before it will answer the purpose of the paper-maker to employ new material, which is not so well

adapted for his purpose as the old, he must be enabled to purchase it for considerably less than it would be worth in the manufacture of textile fabrics; and, besides all this, rags possess in themselves the very great advantage of having been repeatedly prepared for paper-making by the numerous alkaline washings which they necessarily receive during their period of use."

In considering the various processes or stages of the manufacture of paper, we have first to notice that of carefully sorting and cutting the rags into small pieces, which is done by women, each woman standing at a table frame, the upper surface of which consists of very coarse wire cloth, a large knife being fixed in the centre of the table nearly in a vertical position. The woman stands so as to have the back of the blade opposite to her, while at her right hand on the floor is a large wooden box, with several divisions. Her business consists in examining the rags, opening the seams, removing the dirt, pins, needles, and buttons of endless variety, which would be liable to injure the machinery or damage the quality of the paper. She then cuts the rags into small pieces, not exceeding four inches square, by drawing them sharply across the edge of the knife, at the same time keeping each quality distinct in the several divisions of the box placed on her right hand. During this process much of the dirt, sand, and so forth, passes through the wire cloth into a drawer underneath, which is occasionally cleaned out. After this the rags are removed to what is called the dusting machine, which is a large cylindrical frame covered with similar coarse iron wire cloth, and having a powerful revolving shaft extending through the interior, with a number of spokes fixed transversely, nearly long enough to touch the cage. By means of this contrivance, the machine being fixed upon an incline of some inches to the foot, the rags which are put in at the top have any remaining particles of dust that may still adhere to them effectually beaten out by the time they reach the bottom. The rags, being thus far cleansed, have next to be boiled in an alkaline lye or solution, made more or less strong as the rags are more or less coloured, the object being to get rid of the remaining dirt and some of the colouring matter. The proportion is from four to ten pounds of carbonate of soda with one-third of quicklime to the hundredweight of

material. In this the rags are boiled for several hours, according to their quality. The method generally adopted is that of placing the rags in large cylinders, which are constantly, though slowly, revolving, thus causing the rags to be as frequently turned over, and into which a jet of steam is cast with a pressure of something near 30 lbs. to the square inch.

Before considering the subsequent process the material has to go through before it issues from the mill in the finished state of paper, it may be interesting first to describe the position of the machinery in order to show how the work is accomplished.

The following sketches, figs. 317, 318, and 319, represent plans and sections of the machinery part of a paper mill, but none of the outbuildings, such as dry houses, bleach works, and finishing rooms, which are generally attached to the buildings containing the moving power.

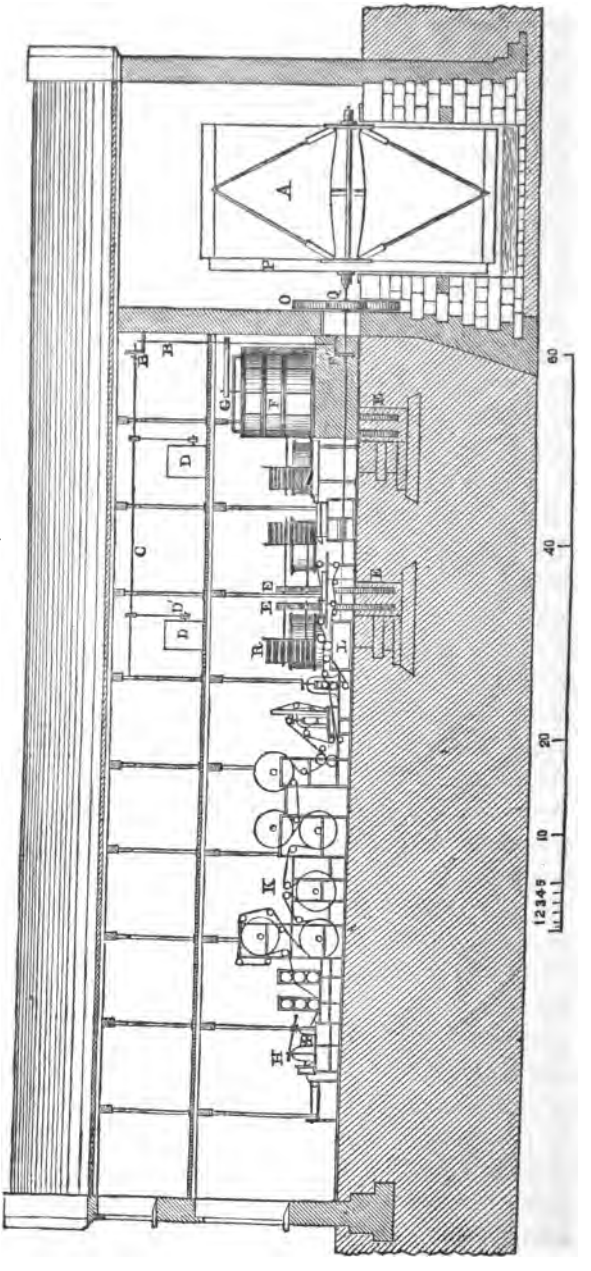
Fig. 317 is an elevation of the mill, showing the water-wheel A, and the principal shafts F, B, C; the vat F, containing the pulp; the rag engines R; the machine L, with endless wire; the drying machine K; the cutting machine H; the rag machines D in the upper story (which are used for cutting and preparing the rags for the boiling and bleaching process); the pillars for supporting the floor and roof; the roof, &c.

Fig. 318 is a plan showing the position and gearing of the longitudinal shafts; *a*, *a*, the pillars for supporting the floor; W, W, the hydraulic presses; T, the bench for sorting the paper; V, the staircase; *b*, *c*, *c*, the method generally adopted for gearing the shafting to the paper machine L; the drying machine K; and the cutting machine H, &c.

Fig. 319 is a section showing the position of the rag engines R R, the upright B, &c.

The building is rectangular, as shown at fig. 318, with a powerful water-wheel A at one end. The mill is 125 feet long, two stories high, and 50 feet wide. It contains dust and rag machines in the sorting-room above; eight engines for converting the rags into pulp; a continuous paper, drying, and cutting machine; hydraulic presses; glazing machines, &c. It will be seen that the water-wheel gives motion to a line of strong cast-iron shafts, varying from 10 to 8 inches diameter, a little above the ground floor. On these shafts, next to the wall, is a bevel

Fig. 317.



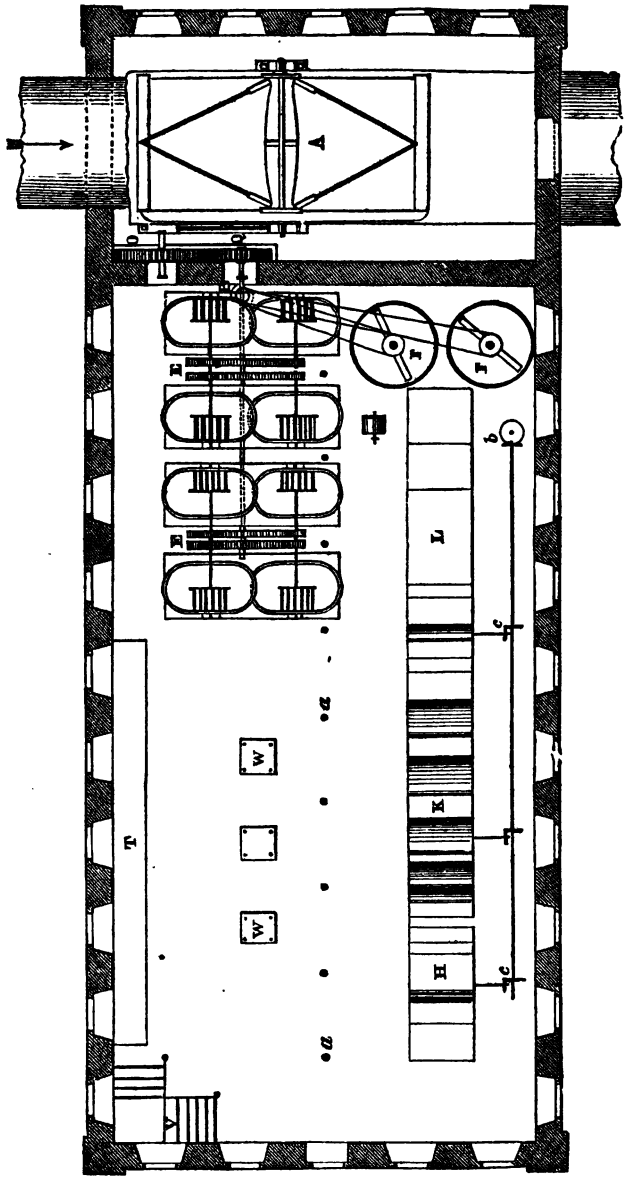
PAPER MILL.

Sectional Elevation.

Fig. 318.

PAPER MILL.

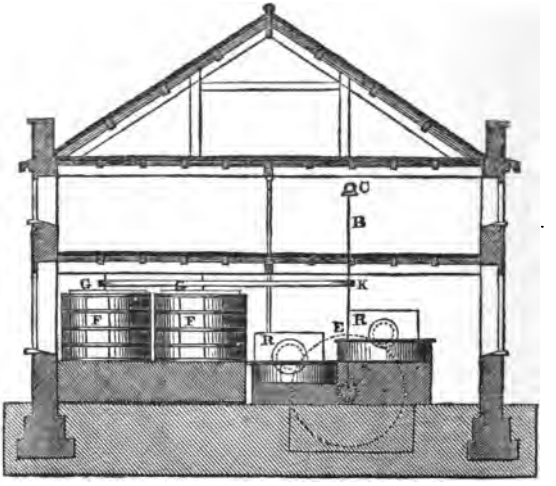
Plan.



wheel for driving the upright B, of cast iron, 5 inches in diameter, and wrought-iron shaft C, $3\frac{1}{2}$ inches diameter, which drive the rag machines D D in the room above. On the line of shafts which pass under the rag or pulp engines are four large spur-wheels E E E E, which give motion to eight pinions $4\frac{1}{2}$ inches diameter, on the axes of the spindles, and also to the cylinders of the rag engines which contain steel cutters fixed all round their periphery. These cylinders, which are about 3 feet diameter, revolve at the rate of 170 revolutions per minute, and,

Fig. 319.

Cross Section.



coming into close contact with similar knives placed at a slight angle in a fixed iron block below, the rags are torn or macerated until they are reduced to the state of pulp. After this process the liquid is run from the higher to the lower engines, where it is comminuted into an exceedingly fine pulp, which in proper time is discharged into a vat or cistern below. From this it is raised by a pump to the vats F over the paper machine, where it is kept in motion by a revolving agitator G, and from thence is run in measured quantities on to the frame and wire-cloth

shaker of the continuous paper machine, where it is finished, dried, and cut into sheets.

Our space does not admit of a full description of the paper-making machine, with all its motions, strainers, rollers, blanket-carriers, &c.; we may, however, direct attention to an elaborate description of these ingenious contrivances in Dr. Ure's "Dictionary," pages 391, 392, to which we have already referred.

The quantity of machinery in a paper mill is not considerable when compared with mills for the manufacture of the textile fabrics, and, with the exception of the paper machine, the drying, cutting, and sizing machines, a mill for the manufacture of paper, so far as its mechanism is concerned, is almost exclusively a piece of well-constructed millwork; the other parts of the manufacture belong to the chemist, both before and after the mechanical operations have been effected.

Connected with the manufacture of paper, there is one point of considerable interest and importance, and that is, what is commonly, but erroneously, termed the *water-mark*, which may be noticed in the Bank of England notes, cheques, and bills, as also in every postage and receipt label of the present day.

On this point Dr. Ure observes that, "Water-marks have at various periods been the means of detecting frauds, forgeries, and impositions, in our courts of law and elsewhere, to say nothing of the protection they afford in the instances already referred to, such as bank notes, cheques, receipt, bill, and postage stamps. The celebrated Curran once distinguished himself in a case which he had undertaken by shrewdly referring to the water-mark, which effectually determined the verdict. And another instance, which may be introduced in the form of an amusing anecdote, occurred once at Messina, where the monks of a certain monastery exhibited, with great triumph, a letter as being written by the Virgin Mary with her own hand. Unluckily for them, however, this was not, as it easily might have been, written upon the ancient papyrus, but on paper made of rags. On one occasion a visitor, to whom this was shown, observed, with affected solemnity, that the letter involved also a miracle, for the paper on which it was written was not in existence until several centuries after the death of the Virgin."

There is, perhaps, no description of manufacture, where machinery is not extensively employed, that embraces a greater variety of forms and quality in its products than paper. Chemical combinations have probably as much, if not more, to do with the manufacture than applied mechanics; and, assuming that we are able to enumerate the different kinds of manufacture, such as writing, printing, and wrapping papers, which come from the mills, we should find in the first, five different sorts, known as cream-wove, yellow-wove, blue-wove, &c.; in printing, two sorts, laid and wove; and in wrapping four, blue, purple, brown, &c. Exclusive of these there are other varieties, such as blotting and filtering papers, which are rendered absorbent by an admixture of woollen rags introduced into the process during the preparation of the pulp, and to these again may be added the appliances to which paper may be moulded under the well-known name of *papier-maché*, which constitutes such a variety of articles of utility and ornament in both the fine and useful arts. This material, when moulded and pressed, can be formed into models, busts, tables, trays, antique candelabra, and a vast variety of useful and classical forms, which, forcibly compressed, is capable of retaining the impressions as originally produced.

The paper manufacture of this country has undergone, like most other manufactures, many changes and improvements. Little more than a century ago the whole manufacture was only equal to two-thirds the consumption, now there is a considerable surplus exported free of duty. In 1835 the weight of manufactured paper that paid duty was . . . . 70,000,000 lbs.
In 1845 it had risen to 124,000,000
In 1855 it stood at nearly 167,000,000
In 1859 it was about 218,000,000
and in six more years it may reach 300,000,000

Such is the importance of this valuable branch of industry, that to every appearance its increase is only circumscribed by the supply of rags and the material employed in the manufacture.

The following table exhibits the speeds of the different shafts and machines shown in figs. 317, 318, and 319:—

List of Wheels and Speeds.

Water-wheel 30 ft. diameter. Velocity on periphery 4 ft. per second, equal to 2·5 revolutions per minute.

Description of Gearing	Driver		Driven		Result
	Diameter	Revolutions	Diameter		Revolutions per minute
	ft. in.		ft. in.		
Segments P .	29 0½	2·5	4 6½		16 revolutions of cross shaft.
Spur-wheels O .	10 6½	16·0	5 6½		30·6 „ „ longitudinal shaft.
Spur-wheels E	11 8	30·6	2 0½		174 „ „ rag engines.
Bevel-wheels F	3 8¾	30·6	2 0½		56·3 „ „ upright shaft.
Bevel-wheels B	3 6	56·3	1 10½		103·7 „ „ longitudinal shaft C.
Pulley D . .	2 0	103·7	1 3		165·9 „ „ rag-cleaning machine.
Pulley K . .	1 0	56·3	3 0		18·7 „ „ agitator.

It will be observed, as noticed in the first part of this work, that the speeds at which water-wheels are driven vary according to the heights of the falls; in this wheel, as in most others adapted to high falls, the speed seldom exceeds 4 feet circumferential velocity, unless there is an unlimited supply, when the speed may be slightly increased.

CHAPTER IX.

POWDER MILLS.

THE manufacture of gunpowder is always a precarious operation, and this is not surprising when we consider the properties and chemical combinations of the ingredients of which it is composed. An admixture of sulphur, nitre, and charcoal in due proportion when fired by a spark, whether accidentally or otherwise, will produce the phenomenon of explosion, and cause serious injury to surrounding objects within range of its destructive effects.

This well-known composition is used for every description of fire-arms, and its safe application depends upon a knowledge of the fact that, at the moment of ignition, violent deflagration takes place, accompanied by the evolution of a large quantity of gas.

The quantity produced by explosion is about 900 times the volume of the powder; but, owing to the high temperature it attains as it passes from the solid to the gaseous state, and the space it occupies at the moment of formation, it is probably three times that amount, or 2,700 times the actual volume of the powder from which it is evolved. This immense increase of volume, and corresponding amount of expansive force, will account for the effects of explosive substances, and the velocity with which a projectile is discharged from a gun. There are many fulminating substances, chiefly compounds of nitrogen and chlorine, besides gunpowder, which explode with great rapidity, the whole mass to every appearance being instantaneously converted into gas. Now this is not the case with gunpowder, as time is an element in its combustion, and it frequently happens that, in a gun loaded with an extra charge of powder, the combustion is incomplete; and hence follows the necessity of limiting the quantity to the power of the gun, in order that the projectile may have the full force of the

exploded powder. This is well known to artillerists, and, also, that no composition fulfils the conditions required in fire-arms so effectually as a well-proportioned mixture of nitre, sulphur, and charcoal. It is this composition which constitutes the propulsive force of projectiles, and the more pure these substances are when properly mixed, the more perfect is the powder.

In powder mills, as in others where chemical operations are carried on, it would be foreign to the objects of this treatise to enter upon the various processes by which a certain article is manufactured from the crude materials of which it is composed; but simply to describe the mechanical operations by which the objects are attained, and that more particularly when it comes within what has been considered the province of the millwright. In treating of this particular manufacture, and the machinery by which its ingredients are mixed, ground, and sifted, which from the time of its invention has been entrusted to the hands of the millwright, it may be interesting to trace, as simply as possible, the preparatory process by which the ingredients already described are manipulated in combination before they arrive at what is called the finished state of gunpowder.

We have noticed that nitre forms one of its principal ingredients, and this is prepared from its crude state, as nitre of commerce, by solution in hot water and crystallisation. By this process, after being carefully washed and every impurity removed, it is in a pulverulent state ready for combination.

Sulphur is prepared by fusion in an iron pot, at a temperature of about 230°; the impurities are then removed by skimming, and the denser parts allowed to sink to the bottom, from whence they are discharged into a receptacle or vessel to cool.

Charcoal, of the three ingredients of gunpowder, is the most important, and much depends on the quality of the wood used. I give the article as it appears in the last edition of Dr. Ure's "Dictionary of Arts and Manufactures."

He states that, "Woods which are best adapted for the production of pyroligneous acid are not fitted for the manufacture of gunpowder; the charcoal must therefore be prepared specially. The following are the essential properties of good charcoal for powder:—1. It should be light and porous. 2. It

should yield little ashes. 3. It should contain little moisture. The woods yielding good powder charcoals are black alder, poplar, spindle tree, black dogwood, and chestnut. Hemp stalks are also said to yield good charcoal for gunpowder.

"The operation of preparing the charcoal naturally divides itself into three processes. 1. The selection of the wood. 2. Preparation of the wood previous to carbonisation. 3. The carbonisation.

"In selecting the wood care is to be taken to avoid the old branches, as the charcoal made from them would yield too much ashes. The bark is to be rejected for the same reason. The wood is to be cut into pieces from 4½ feet to 6 feet long. If the branches used are more than ¾ of an inch in diameter they are to be split. If the wood be too large, great difficulty will be found in uniformly charring it.

"There are two methods employed in the charring of wood for gunpowder. In one, the operation is conducted in pits; but the process more commonly resorted to is distillation in cylindrical iron retorts. There are certain advantages in the pit process, but they are more than counterbalanced by the convenience and economy of distillation. The stills used are about 6 feet long, and 2 feet 9 inches in diameter. The ends of the cylinders are closed by iron plates, pierced to admit tubes of the same metal. Some of the latter are for the introduction, during the carbonisation, of sticks of wood, which are capable of being removed to indicate the stage of the decomposition, while another communicates with the condenser. The more freely the volatile matters are allowed to escape, the better the quality of the resulting charcoal. If care be not taken in this respect, especially as the distillation reaches its close, the tarry matters become decomposed, and a hard coating of carbon is deposited on the charcoal, which greatly lowers its quality. The process of burning in pits is considered to yield a superior coal, owing to the facility with which the gases and vapours fly off.

"The degree to which the burning or distillation is carried materially influences the nature of the resulting powder. If the operation be arrested before the charcoal becomes quite

black, so that it may retain a dark-brownish hue, the powder will be more explosive than it would be if it were pushed until the charcoal had attained a deep black colour. When it has been found that no more volatile products are being given off, the fire is damped, and in a few hours the contents of the cylinders are transferred to well-closed iron boxes to cool."

The three ingredients having been carefully prepared are now mixed so as to effect a thorough incorporation necessary for the production of good powder. The original method was by stampers shod with brass beaters working in wooden mortars, the stampers in this case being raised by a revolving shaft and tappets worked by a water-wheel, or horses, as most convenient.*

The government powder mills at Waltham Abbey, and other private establishments, have not, until of late years, undergone any material improvement since their erection. They could not, however, escape the changes which for the last twenty years have been in operation in almost every other kind of manufacture. New contrivances and improvements upon old ones have been applied to powder mills as well as to those of a different character; and although the system of grinding by edge stones has not been superseded, great improvements have nevertheless been introduced, by substituting turned cast-iron rollers or runners in place of edge stones, and these revolving on turned cast-iron beds give greatly increased accuracy to the movements, and less danger from sparks or small crystals from the runners than when composed of stone. As this kind of machinery has been renewed at Waltham Abbey, a descrip-

* In the year 1839 the author visited Constantinople, at the request of Sultan Mahmoud, for the purpose of inspecting and reporting upon the then existing state of the founderies, fire-arms manufactory, powder mills, &c.; and during this investigation he found the powder mills driven by relays of horses, working in the interior of large wooden wheels, the same as a dog-spit. About the same time steam engines were introduced for working the machinery at a distance by compressed air. The engine, boilers, air cylinder, &c. were in this case at a distance of 200 yards from the machinery, in order to prevent accident. This arrangement was subsequently changed, as it was found that more than one-half the power of the engine was lost, by friction, in forcing the air through the pipes, and working it over again into cylinders giving motion to the machinery at that distance from the motive power.

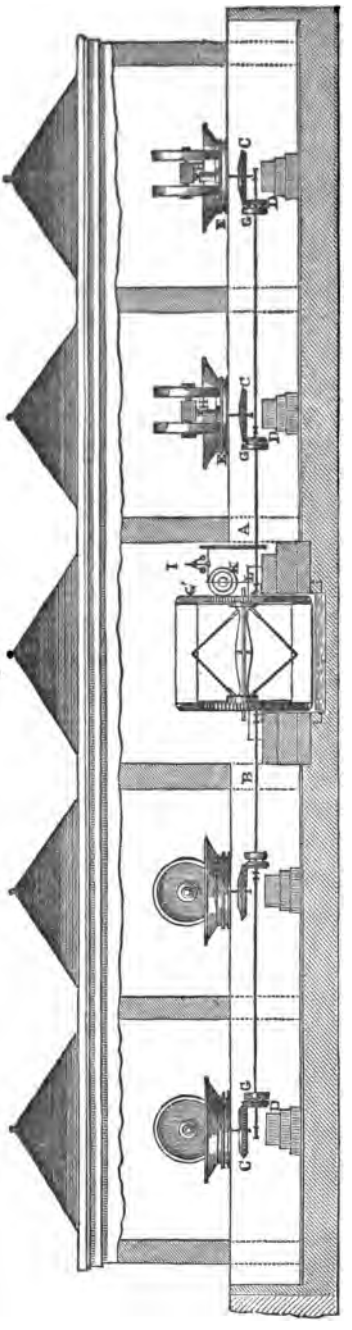


Fig. 320.

tion of the arrangements and improvements introduced by Mr. Anderson, of Woolwich, and others, may not be without interest.

Two entirely new establishments were constructed under the direction of these gentlemen by Messrs. W. Fairbairn and Sons, of Manchester, and Messrs. B. Hick and Co. of Bolton, the former executing the water-wheels, edge runners, hydraulic presses, and granulating machines; the latter a 40-horse power steam engine and six pairs of edge runners.

In the construction of powder mills, it is a question of much importance to have the grinding and other processes separate from each other, that in case of explosion in any one department it should not communicate to the others. This precaution has been considered essential in every well-regulated powder mill, and to attain that object, most establishments have their mills at 100 to 150 yards distant from each other. Where this arrangement is found inconvenient, and the mills have to be nearer together, they are then separated by butts or mounds of earth, at a considerable height, and tapering at the top like the roof of a house. The more recent erections are, however,

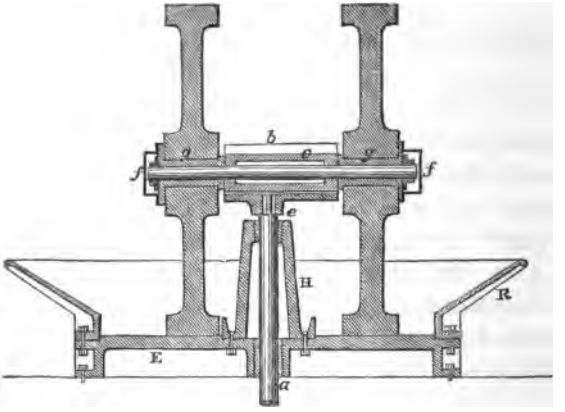
different since the introduction of the cast-iron runners, as may be seen by the preceding arrangement, fig. 320, where the mill is driven by a water-wheel.

On this plan it will be observed, that the water-wheel is 14 feet diameter, 12 feet wide inside the buckets, with segments on the shrouds, giving motion to two pairs of runners on each side of the water-wheel. Each pair of runners is in a separate house, covered with a light iron roof, and partitioned from each other by a thick wall, intended in case of explosion to save the adjoining mill. How far this arrangement will answer the purpose has not been determined, as no explosion has taken place since the mills were finished, and there is therefore no proof of the amount of security afforded, nor of the direction of the explosion, which, it is expected, would be vertical through the roof. It will be observed that the water-wheel gives motion to a line of shafts A and B, fig. 320, one on each side of the water-wheel placed in an underground tunnel, and by the bevel wheels C, D, gives motion to the vertical spindle which passes through a tight brass stuffing box (see also fig. 321) in the large bed plates E E, and gives motion to the edge runners above; the spindle in this case being steadied by the conical standard H, into which is inserted a brass bush for that purpose. The pinion on the tunnel shaft is bored and keyed upon the sliding clutch G, which works by friction on the principle described at page 92 of this work. All the wheels in these mills have wood and iron teeth, as iron working into iron is always attended with danger, where they are liable to come in contact with particles of powder. The bed plates on which the runners revolve rest upon the side walls of the tunnel, and the apparatus for starting and stopping the runners (which consists of a worm-wheel and crank) is worked by a wheel and handle from the outside.

In order to illustrate more in detail the method of constructing the mixing mill, and the connection between the vertical shaft and the runners, fig. 321 has been introduced. E is the bed plate, which is grooved out to admit the conical standard H. The inclined side R is bolted to the bed plate E, which contains the brass bush *a*. The standard is bolted to the bed plate with countersunk headed bolts, and a brass bush, *e*, is firmly inserted

in its upper extremity to steady the vertical spindle. A box, *b*, planed in the inside and keyed on to the vertical spindle, in which another square brass box is allowed freely to slide, forms the connection between the spindle through the runner and the vertical shaft. A brass bush, *g*, is driven into the runner, which is prevented from sliding off the spindle by a collar through which a split pin is driven. A brass cap, *f*, bolted to the collar of the brass bush, completes the mill. The object of this cap is to prevent any grease from falling into the powder.

Fig. 321.



Scale $\frac{1}{4}'' = 1$ foot.

The water-wheel is on the ventilated principle, applicable to a variable fall, which does not exceed 3 feet in low ebbs; at other times, when the river is flooded, there is a large supply of water and a considerable increase of head. The runners are regulated by the governor I, which acting upon the worm wheels K, L, communicates motion to the shuttle, which moves upon the back surface of the cast-iron breast, and increases or diminishes the supply to the wheel, as may be necessary to maintain a steady uniform motion in the machines. It will be observed that the iron runners are not equidistant from the vertical spindle which carries them round on the surface of the bed plate. This is for the purpose of grinding the ridges which are thrown up by the outer edge of the central runner, and

with the aid of scrapers the powder is brought immediately under the runners, the more effectually to incorporate the mixture of the ingredients. During the grinding, the powder is kept moist by a little water at proper intervals, to make the particles adhere together, and form the mass into a sort of paste.

Another water-wheel is employed to give motion to the hydraulic presses, crushing, sifting, and granulating machines; and these operations are carried on by a series of machines, adapted to the different kinds of powder which the Government requires for small arms and cannon. Other methods, besides those of edge stones or cast-iron runners, have been called into use for effecting the thorough incorporation of the ingredients for the production of good gunpowder, but none of them have been found to answer so well as the cast-iron runners or edge stones; the only objection to the edge stones being their liability to strike fire.

Previous to the grinding and mixing process under the runners, the ingredients have to be pulverised, which is accomplished by means of a number of revolving drums and balls. The pulverised materials require to be sifted in cylinders in order to be properly mixed; and this completes the preparatory processes, and renders the compound ready for grinding.

The subsequent processes as described by Dr. Ure are as follow:—

"The cake produced by the action of the stones is ready for graining or corning. For this purpose the cake is subjected to powerful pressure by means of an hydraulic press. The mass is then broken up and transferred to a species of sieve of skin or metal pierced with holes. A wooden flail is placed on the fragments, and the sieves are violently agitated by machinery. By this means the grains and dust produced by the operation fall through the holes in the skin or metal discs, and are afterwards separated by sifting. Sometimes the machinery is so arranged that the graining and separation of the meal powder is effected at one operation. The meal powder is reworked, so as to convert it into grains. The next operation to which the powder is subjected is glazing. Its object is to render it less liable to injury, by absorption of moisture or disintegration

during its carriage from place to place. The glazing is effected by causing the grained powder to rotate for some time in a wooden drum or cylinder, containing rods of wood running from end to end. The grains, as they rub against each other and against the wooden ribs, have their angles and asperities rubbed off, and at the same time the surface becomes harder and polished. It is finally dried by exposure to a stream of air, heated by means of steam."

The following Table shows the composition of the various gunpowders in use amongst the different nations of Europe and America:—

TABLE OF THE COMPOSITION OF VARIOUS GUNPOWDERS.

	Nitre	Sulphur	Charcoal
English war powder	75·0	10·0	15·0
„ sporting powder	77·0	9·0	14·0
French war powder	75·0	12·5	12·5
„ sporting powder	76·9	9·6	13·5
„ blasting „	62·0	20·0	18·0
„ „ „ (another kind)	65·0	20·0	15·0
United States war powder	75·0	12·5	12·5
Prussian war powder	75·0	11·5	13·5
Russian „ „	73·8	12·6	13·6
Austrian „ „	75·0	10·0	15·0
Spanish „ „	76·5	12·7	10·8
Swedish „ „	75·0	16·0	9·0
Chinese „ „	75·7	14·4	9·9

It will be seen from the above that the different nations do not materially differ in the proportions at which they have arrived by experience. They approximate nearly to each other, and the differences which exist may be accounted for by the superior or diminished purity of the substances of which they are composed. We regret to remark that the limits of our treatise preclude us from taking advantage of the drawings of the granulating machines, presses, &c. in our possession.

For the speed of the runners, and of the shafting and governor gear, we beg to refer the reader to the annexed list of wheels and speeds which enter into this description of Powder Mills:—

List of Wheels and Speeds.

Description of Gearing	Driver		Driven	Result Revolutions per Minute
	Diameter	Revolutions	Diameter	
	ft. in.		ft. in.	
Water-wheel .	14 0	—	—	6·68 revolutions per minute, equal to 4·89 ft. per second.
Segments G' .	12 9	6·68	3 6½	24·2 revolutions of main horizontal shaft.
Bevel-wheel C .	2 3	24·20	5 4⅝	10 revolutions of runner.
Governor Gear.				
Pulley H . .	1 9	24·20	1 2	36 revolutions of governors.
Worm-wheel K	0 4	36·00	0 8¼	1·79 „ vertical shaft.
Worm-wheel L.	0 5	1·79	2 0	0·031 „ rack shaft.

It might have been interesting to have noticed in this place a new process of manufacture which to some extent is superseding the use of gunpowder, and that is gun-cotton, first invented by Professor Schonbein, and now greatly improved by General von Linz and the Austrian Government; but as that manufacture is now under the consideration of the authorities at Woolwich, and as experiments are instituted for the purpose of analysing its constituents, and testing its powers as compared with our best qualities of gunpowder, it would be premature in this stage of investigation to venture an opinion upon its comparative merits as a substitute for the present compounds.

CHAPTER X.

IRON MILLS.

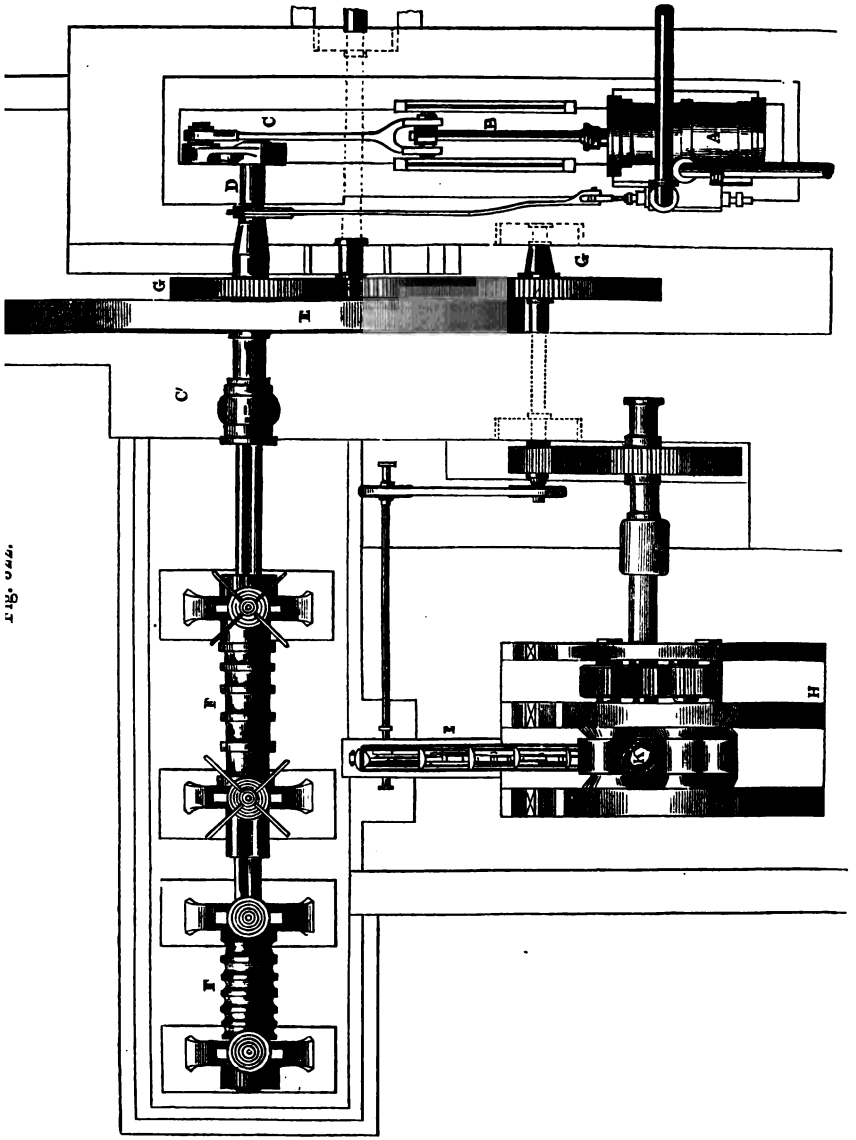
THE mechanical operations connected with the manufacture of wrought-iron consist of shingling, hammering, rolling, &c.; to which we may add the forging of "uses;" that is, the forging of those peculiar forms which constitute the frames and parts of steam engines, iron ships, railway carriages, locomotives, &c., required in those important constructions.

In tracing the whole of the processes in the manufacture of wrought-iron bars and plates, it will not be necessary to dwell on those practices which have been superseded by more modern and improved machinery. Suffice it to observe, that the puddled balls have to be fashioned into oblong slabs or blooms by the blows of a heavy forge hammer. During this operation, the scoria and impurities contained in the balls are separated from them in the shape of scoria by the force of impact, and by a continued series of blows the iron is rendered malleable, dense, and compact. The slabs are then passed through a series of grooved iron rollers, which reduce them to the form called puddle bars. These are again cut up and piled regularly together, or faggoted, and brought to a welding heat in the reverberatory furnace, when they are a second time passed several times through grooved rollers, and by this latter process are made into bars or rails ready for the shears. In the manufacture of plates the same process of heating and piling is observed, with this difference, that the pile at a welding heat is passed through plain surface rolls until the required thickness and dimensions are attained.

In order to arrive at a clear conception of the mechanical operations employed in the manufacture of iron,* it will be necessary to describe more at length the processes as at present practised, with the improved and powerful machinery now employed; and as much depends upon the application of the

* For further description of the different processes, see the author's work on Iron Manufacture, second edition, 1865.

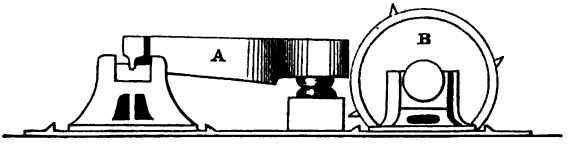
motive power, the steam engine claims the first notice. Until of late years the vertical steam engine was invariably used for giving motion to the forge hammer and rolling mill, which were placed on one side of the fly-wheel and the hammer on



the other; but the high-pressure non-condensing engine is found to be decidedly preferable, as the waste heat passing from the puddling and heating furnaces is quite sufficient to raise the steam for working the rolls and one of Brown's bloom squeezers, as shown in the preceding drawing:—

In this arrangement, the cylinder A (fig. 322) is placed horizontally, and is supplied with steam from boilers near the puddling furnaces. The piston rod and slides B, and connecting rod C, give motion to the crank shaft D, on which is fixed a heavy fly-wheel, E. The puddling rollers F F are driven direct from the end of the fly-wheel shaft, being attached to it by a disengaging coupling, C'; the bloom squeezer H is driven by a train of spur-wheels, G G. Under the lower rolls of the squeezers, a Jacob's ladder or elevator, I, is fixed, for raising the block, which, deprived of its impurities, is reduced to an oblong shape by passing between the rollers of the squeezers. The block on leaving the rollers is carried in front of one of the projecting divisions of the ladder I, and thrown on to the platform in front of the rollers F F; the workman then seizes it with a pair of tongs, and forces it into the largest groove in the rolls; it is then passed in succession through the other grooves till it attains the required form of the bar. This squeezer process is substituted for the old method of preparing and shingling the puddle balls, still much practised from its simplicity in reducing them to shape by a heavy hammer called the forge hammer or helve, shown in fig. 323. It consists of a

Fig. 323.



heavy mass of iron, A, resting on a pivot at one end, and lifted by projecting cams on a revolving wheel, B, at the other: between these points, and nearer the front, is the anvil on which the puddler's ball is thrown to receive a rapid succession of strokes, which force out the impurities, and reduce it to a form suitable for insertion between the rolls.

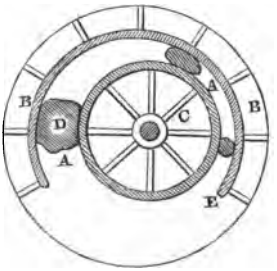
Other squeezers have also been used for the same purpose, one of them consisting of two massive jaws worked by a lever and crank, between which the ball is moulded by severe pressure to the necessary form. The squeezer is, however, alleged to have the effect of lapping up cinder in the iron to a greater extent than in the case of the forge hammer. This instrument is sometimes called the alligator, from its resemblance to the mouth of that animal; and it will be observed that the puddle ball is reduced in size by being rolled by the puddler to the back part of the jaws, where the leverage is more powerful as its diameter decreases.

One of the most perfect machines of this class is Brown's bloom squeezer, already referred to. The heated ball of puddled iron, K, thrown on the top of the machine, is gradually compressed between the revolving rollers as it descends, and at last emerges at the bottom, where it is thrown on to the movable "Jacob's ladder" I, fig. 322, by which it is elevated and discharged in front of the rolls, as already described. This machine effects a considerable saving of time; it will do the work of twelve or fourteen furnaces, and may be kept constantly going as a feeder to one or two pairs of rollers.

There are two distinct forms of this machine: one in which the bloom receives only two compressions; and the other, which is much more effective, where it is squeezed four times before it leaves the rolls and falls upon the Jacob's ladder.

There is another machine for preparing the blooms by com-

Fig. 324.

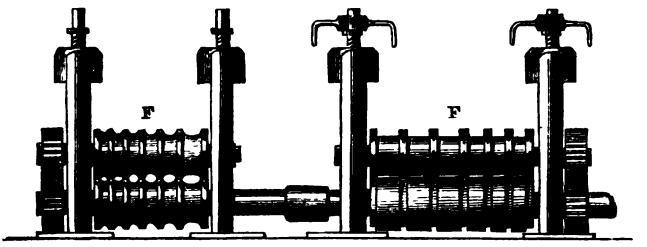


pression, namely, a table firmly embedded in masonry, as shown at A A, fig. 324, with a ledge rising up from it to a height of

about 2 feet, so as to form an open box. Within this is a revolving box, C, of a similar character, much smaller than the last, and placed eccentrically in regard to it. The ball or bloom D is placed between the innermost revolving box C and the outer case A A, where the space between them is greatest, and is carried round till it emerges at E, compressed and fit for the rolls.

The bloom, after leaving the hammer or squeezer, is at once placed in the rolling mill, fig. 325. This consists of massive

Fig. 325.



grooved rollers connected by toothed pinions, and put in motion by the steam engine. The rollers are fixed in massive framing, which has to support a prodigious strain, as the bloom is drawn in, and compressed and elongated as it passes through. The bar so formed is passed through a succession of similar grooves, decreasing in size till it is reduced to about 4 inches wide, three-quarters to an inch thick, and 10 or 12 feet in length. In this state it is cut to pieces, piled, heated, &c., as already described, and a second time rolled. The bars produced by this second process are called merchant bars; or the bloom may be rolled into plates. Again, instead of being rolled, it may be brought under the steam hammer and forged into *uses*, or those variously shaped masses of wrought-iron which are employed by the engineer, millwright, or iron ship builder, where these *uses* are extensively employed. We have stated that the horizontal, non-condensing steam engine, from its compact form and convenience of handling, is admirably adapted for giving motion to the machinery of iron works. For this object it is superior to the beam engine, as its speed can be regulated with the same facility as the condensing engine by simply

moving the lever of the steam valve, so as to suit all the requirements of the manufacturer, under the varied conditions of pressure, and the power required for rolling heavy plates or bars. It is also much cheaper in its original cost, and all its parts being fixed upon a large bed plate, requires a comparatively small amount of masonry to render it solid and secure.

In regard to the manufacture of the rollers for the boiler plate, and merchant train, the greatest care must be observed in the selection of the iron and the mode of casting. In Staffordshire there are roller makers, but in general the manufacturer casts his own; and as much depends upon the metal, the strongest qualities are carefully selected and mixed with Welsh No. 1 or No. 2, and Staffordshire No. 2. This latter description of iron, when duly prepared, exhibits great tenacity, and is well adapted, in either the first or second melting, for such a purpose. In casting, the moulds are prepared in loam, and when dry are sunk vertically into the pit to a depth of about 5 feet below the floor. The moulding box is surrounded by sand firmly consolidated by beaters, and a second mould or head is placed above it, which receives an additional quantity of iron to supply the space left by shrinking, and retain the roll under pressure until it solidifies, and thus secures a great uniformity and density in the roller. The metal is run into the mould direct from the air furnace by channels cut in the sand; and immediately the mould is filled, the workman agitates the metal with a rod, in order to consolidate the mass and get rid of any air or gas which may be confined in the metal. This stirring with iron rods is continued till the metal cools to a semi-fluid state, when it is covered up and allowed slowly to cool and crystallize. This slow rate of cooling is necessary to favour a uniform degree of contraction, as the exterior closes up like a series of hoops round the core of the casting, which is always the most porous and the last to cool. In every casting of this kind, it is essential to avoid unequal contraction; and this cannot be accomplished unless time is given for the arrangement of the particles by a slow process of crystallization. Rollers for boiler plates and thin sheet iron are difficult to cast sound, on account of their large size. They are subjected to very great strain, and require to be cast from the most

tenacious metals. The bearings or neck should be enlarged, or turned to the shape shown at A A, and the cylindrical part B for

Fig. 326.

plate rolls should be slightly concave, because when the slab is first passed through the rollers, it comes in contact with a small portion only of the revolving surface. The central parts of the roller thus become highly heated, whilst their extremities are perfectly cool. The consequence is, that the expansion of the roller is greatest in the middle; and unless this be provided for by a concavity in the barrel, the plates become buckled—that is, both warped and uneven in thickness, and, consequently, imperfect and unfit for the purposes of boiler making. Bar rolls are generally cast in chill; and great care is required to prevent the chill penetrating too deep, so as to injure the tenacity of the metal and render it brittle.

There are different kinds of rolling mills used in the iron manufacture, and they vary considerably in their dimensions, according to the work they have to perform. The first, through which the puddled iron is passed, we have already described as puddling rolls. There are others for roughing down, which vary from 4 to 5 feet long, and are about 18 inches diameter; those for merchant bars, about 2 feet 6 inches to 3 feet long, and 18 inches in diameter, are in constant use. The boiler plate and black sheet iron rolls are generally of large dimensions; some of them for large plates are upwards of 6 feet long and 18 to 21 inches in diameter; these require a powerful engine and the momentum of a large fly-wheel to carry the plates through the rollers; and not unfrequently, when thin wide plates have to be rolled, the two combined prove unequal to the task—and the result is, the plates cool and stick fast in the middle. The greatest care is necessary in rolling plates of this kind, as any neglect of the speed of the engine or the setting of the rolls results in the breakage of the latter, or bringing the former to a complete stand.

The speed of the different kinds of rolling mills varies according to the work they have to perform. Those for merchant bars make from 60 or 70 revolutions a minute, whilst those of large size, for boiler plates, are reduced to 28 or 30.

Others, such as the finishing and guide rollers, run at from 120 to 400 revolutions a minute. In Staffordshire, where some of the finer kinds of iron are prepared for the manufacture of wire, the rollers are generally made of cast-steel, and run at a high velocity. Such is the ductility of this description of iron, that in passing through a succession of rollers, it will have elongated to ten or fifteen times its original length, and, when completely finished, will have assumed the form of a strong wire of $\frac{3}{8}$ to $\frac{1}{4}$ of an inch in diameter, and 40 to 50 feet in length.

A high temperature is an indispensable condition of success in rolling. The experience of the workman enables him to judge, from the appearance of the furnace, when the pile is at a welding heat, so that, when compressed in the rolls, the particles will unite. Sometimes it is necessary to give a fine polish or skin to the iron as it leaves the rolls; but this can only be done when the iron cools down to a dark red colour, and by the practised eye of an intelligent workman.

Another description of rolling for giving a fine skin or polish to the iron is to roll it cold; and this process not only adds to its appearance, but it increases its tenacity, and renders it suitable for many purposes, such as slender shafts where stiffness is required.

Before closing this description of the manufacture of iron as relates to the rolling mill, the whole process would be incomplete if the new appliance for rolling of large masses into enormous plates were omitted. The casing of ships of war with enormously large and thick plates is a new discovery in the art of war, and its appliance, not only to ships, but forts and citadels, presents an entirely new era in the history of naval and military tactics. To what extent its future development may attain, time alone can determine; but of this it is quite evident, that a change of construction and a new system of operations in the laws of defence and attack are imminent. We have, therefore, to prepare new mills and new manufactories upon a scale commensurate with the wants and requirements of the changes now in progress. To what extent the present transition may be carried is unknown, as everything depends on future developments in the manufacture of guns and the antagonistic force of iron in its

powers of resistance to the increased power of projectiles at high velocities. But however this may be, the enterprise, power, and energy of the British manufacturers, as instanced in the works of Beale and Brown, are fully able to meet the emergency, and to roll plates of any dimensions required for the purpose of defence.

As an example of this determined spirit we may notice a series of experiments which took place in presence of the Lords of the Admiralty, at Messrs. John Brown and Co.'s works, Sheffield, in April 1863. For some time previous both Messrs. Beale and Brown had been making preparations for the rolling of these plates; and in order to put the reader in possession of the experiments at Messrs. Brown's works, we have given in Appendix III. a graphic description of the whole process as taken from the correspondent of the 'Times,' who was present on the occasion.

APPENDIX.

NO. I.

A NEW system of frictional gearing for the transmission of power has recently been introduced by Mr. James Robertson, of Glasgow, which from its novelty and application to the purposes of the millwright is deservedly entitled to notice. Mr. Robertson's system consists of a series of wheels or pulleys with smooth surfaces rolling on each other by frictional contact. The peripheries are formed into concentric wedge-shaped surfaces, one having projectional knife-formed edges, and the other a V-shaped groove in which the former rolls. On this principle the teeth of the wheels are entirely dispensed with, and the driving wheel gives motion to that driven by the simple adhesion of the two surfaces. The projecting surfaces of the wheels are generally formed or turned to an angle of 40°, which, running in the corresponding grooves of other wheels —also formed to the same angle—produces lateral contact and greatly increases the adhesive force when acted upon by the same amount of pressure as that given to flat surfaces.

This principle of gearing embodies all the forms given to spur and bevel gear. It is as equally applicable to internal as to external gear, and it may be applied in a variety of forms to coupling shafts, sliding clutches, &c., for the disengaging of machinery. In illustration of this principle we have selected forms and figures which show very distinctly the mode in which Mr. Robertson brings the peripheries of his wheels in contact, and the system adopted for the transmission of power.

Figs. 1 and 2 are a side and front elevation of a pair of spur wheels in gear, showing the wheels in contact at the points *a*, *a*, in their respective grooves.

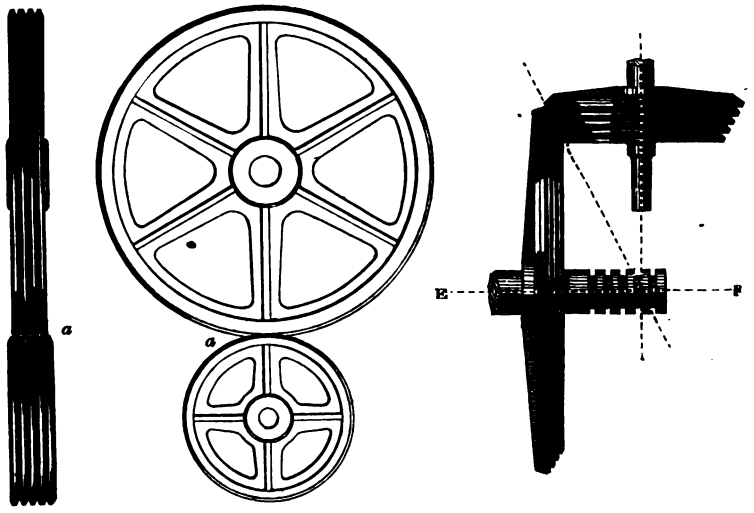
Fig. 3 is a pair of bevel wheels also in gear, showing their general forms and proportions with the grooved bearing on the shaft E F to keep them in gear and relieve the thrust on the rim.

Fig. 4 is an enlarged sectional drawing of the acting surfaces of a pair of spur wheels, and fig. 5 an enlarged sectional view of the rims of a

pair of bevel wheels, both formed at the angle of 40°, there being no difference in Mr. Robertson's practice in the form of bevel-wheel surfaces from that of spur wheels.

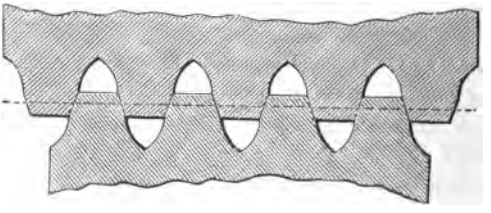
With the surfaces thus formed, and after being wrought for some time

Fig. 1. Fig. 2. Fig. 3.



together and thoroughly cleaned and fitted, the bite or hold of the surfaces is fully $1\frac{1}{2}$ times the force exerted in holding them in contact; and in practice, where the wheels are not less than 2 feet diameter, a

Fig. 4.

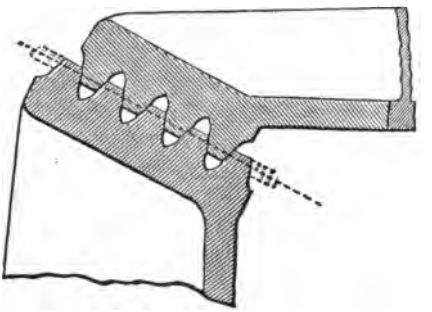


pressure equivalent to the power required to be transmitted is all that is wanted to retain the wheels in contact and to secure the necessary adhesion without slipping.

Mr. Robertson states that a pressure of $1\frac{1}{2}$ tons is sufficient to transmit 100 indicated horse power with wheels working at a speed of

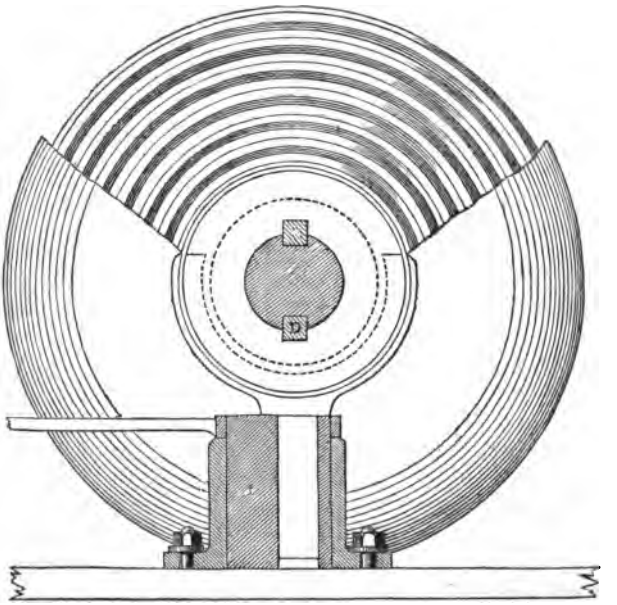
1,000 circumferential feet per minute. The pressure upon the bearings may be obtained from simple formulæ calculated to meet the irregularities of resistance and maintain the adhesion of the surfaces in the

Fig. 5.



ratio of the applied force and the resistance respectively to be overcome. The pitch or width of groove is proportioned to the diameters of the wheels and the work to be done—ranging from $\frac{1}{2}$ an inch to $2\frac{1}{2}$ inches—

Fig. 6.

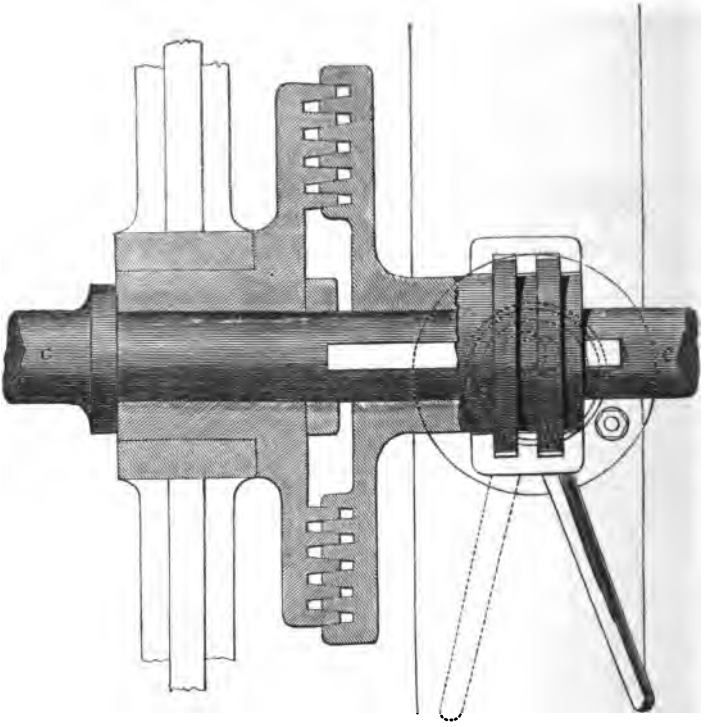


and the breadth of rim generally employed for transmitting a given amount of power is slightly greater than that of ordinary cog-wheels.

In practice however it has been found difficult to establish any reliable formulæ for transmitting a given amount of power on the principle of cog-wheels; but we may safely infer that this will shortly be accomplished when the frictional principle is more extended, and when more reliable data is obtained for that purpose.

The durability of frictional wheels depends as much on the quality or hardness of the metal used as on the breadth of surface, and for small

Fig. 7.



diameters a description of hard cast iron is used which is unsuitable for casting wheels of large dimensions. At slow speeds, where the pressure to maintain the driving contact is necessarily greater than at high speeds, the pitch of the groove and the strength of the rim is proportionately increased; but the necessary breadth of surface for transmitting a given amount of power does not depend on the enlarged surface of adhesion to produce certain effects, as high speeds and light pressure appear from Mr. Robertson's practice to be decidedly preferable to transmit large in-

crements of work. In the first of two examples quoted by him, where the power transmitted is 300 indicated horse power, the breadth of surface is 14 inches with a circumferential velocity of 600 feet per minute. In the second the velocity was 2,000 feet per minute with a reduced surface, and both appear to have worked exceedingly well.*

We might enlarge at considerable length on the application of this system applied to rolling-mills, fans, pumps, &c., but we prefer merely to allude to the friction clutch, and leave Mr. Robertson to speak for himself as to the merits of the new system. The form of clutch given in figs. 6 and 7 consists of two discs placed on a shaft or spindle, having their inside surfaces formed into concentric wedges and grooves, and at such relative distances from the centre of the shaft as, on their being pressed together, to make the concentric wedges of the one disc enter the corresponding grooves of the other, and produce thereby a wedging contact, in principle the same as that applied in wedged and grooved frictional wheels. The action, however, differs in so far as the surfaces of these clutches do not roll on each other like the surfaces of wheels, but is simply a method of *uniting* one surface to another. The drawing represents the form of these clutches most generally used and suited for general clutching purposes; but there are many modifications adapted to suit particular purposes, especially in relation to the modes of throwing them in and out of contact.

They transmit power efficiently, and connect and disconnect without jarring action, although the shafts on which they are placed are working at high speeds. As a very slight amount of shift connects or disconnects them, the arrangement of fork, or connecting hand-lever movement, effects the engaging and disengaging actions with quick action and with little effort.

The diameter of these clutches usually employed for transmitting the power of any shaft is seven times the diameter of the necks of the shafts—that is, a malleable iron shaft 2 inches diameter requires a clutch 14 inches diameter to be equal to it in its resistance to torsion; and the same proportion for all other sizes is maintained. Where motion has to be transmitted from one part of a line of shafts to another part, or to connect and disconnect a loose wheel working on the same shaft (which is the object of the clutch as arranged and represented in figs. 6 and 7), this form of clutch is the most simple and efficient. The surfaces of these clutches are kept slightly lubricated, but only require oil at long intervals, and merely to keep them from becoming entirely dry.

Mr. Robertson states, 'that the smoothness of action depends very much on the nature of the foundations and bearings as well as the position

* The pressures on the surfaces in these cases were not given.

of the wheels to each other and description of building in which they are placed. The best positions for main gearing are where the axes are on one level, placed in one cast-iron sole plate and on stone foundations, or placed in cheek-frames such as are extensively manufactured by the Patent Frictional Gearing Co. for circular saws, &c. Fitted up in this way a circumferential speed of about 2,000 feet per minute works noiselessly, but such high speeds are not attainable in common mill gearing set up in wall boxes, without risk of vibration and noise.

One of the chief advantages of this system is the facility it gives for throwing the wheels in and out of gear while in motion without jarring action or liability to fracture, thus serving in a simple way at the same time the purposes of driving wheels and of a disconnecting and connecting clutch. In this way the system has been extensively applied by Mr. Robertson to winding engines, hoists of all kinds, and similar purposes where disconnecting gear is required. Among the largest and best examples of this kind are the winding engines at Dunmore Collieries near Musselburgh; the winding engines at the Washington Collieries near Newcastle-on-Tyne, designed by Mr. Easton of Westhouse, Gateshead; and for the main gearing of two dredgers employed for deepening the River Tyne, designed by Mr. J. F. Ure, C. E., of the River Tyne Commission.

A good deal has also been done in the application of this system to rolling-mills, the small risk from fracture which this gearing affords being the chief reason of its being employed for these purposes. The heaviest and best examples may be seen in the Charles Street Works of the Glasgow Iron Company, Glasgow, being used there for 5, trains of rolls varying from 16 to 8 inches diameter.

The same principle of wedge surfaces is applied by Mr. Robertson to disc clutches in various forms and makes a very efficient clutch.

It is evident that for the success of this system much depends on accuracy of workmanship, on having the wheels truly hung, and having the bearings well adapted for maintaining the driving contact. Considerable progress seems already to have been made in this direction, and the constant occurrence of new applications of this system will no doubt gradually develop these details.

It is stated further by Mr. Robertson that where the diameters of the wheels are moderately large there is no greater loss of power than by the use of cog-wheels, and very considerably less waste of power than by the use of straps.

NO. II.

THE following extracts, taken from a paper by Mr. EDWARD BAINES, M.P., on the Woollen Manufacture of Leeds, read at the Meeting of the British Association for the Advancement of Science in 1858, will be found interesting:—

In giving a description of the different processes, Mr. Baines states—'That the processes of the Woollen Manufacture are more numerous and complex than those of any other of our textile manufactures. In one of those complete and beautiful establishments where fine cloth is both manufactured and finished—as that of Messrs. Benjamin Gott and Sons of this town, which has long ranked with the first woollen factories of any country—the spectator who may be admitted to it will see all the following processes, namely:—

1. Sorting the wool; no less than ten different qualities being found in a single fleece.

2. Scouring it with ley and hot water, to remove the grease and dirt.

3. Washing it with clean cold water.

4. Drying it; first in an extractor—a rapidly revolving machine full of holes—and next, by spreading it and exposing it to the heat of steam.

5. Dyeing, when the cloth is to be wool-dyed.

6. Willying, by revolving cylinders armed with teeth, to open the matted locks and free them from dust.

7. Teasing, with a teaser or devil, still further to open and clean.

8. Sprinkling plentifully with olive oil, to facilitate the working of the wool.

9. Moating, with a moating-machine, to take off the moats or burs, i.e. seeds of plants or grasses which adhere to the fleece.

10. Scribbling, in a scribbling-machine, consisting of a series of cylinders clothed with cards or wire-brushes working upon each other, the effect of which is still further to disentangle the wool and draw out the fibres.

11. Plucking, in a plucking-machine, more effectually to mix up the different qualities which may remain in the wool.

12. Carding, in a carding-machine, resembling the scribbler, but more perfectly opening the wool, spreading it of a regular thickness and weight, reducing it to a light filmy substance, and then bringing it out in cardings or slivers about three feet in length.

13. Slubbing, at a frame called the billy, generally containing sixty spindles, where the cardings are joined to make a continuous yarn, drawn out, slightly twisted, and wound on bobbins.'

[By a new machine, called the Condenser, attached to the carding-machine, the wool is brought off in a continuous sliver, wound on cylinders, and ready to be conveyed to the mule, so as to dispense with the billy.]

'14. Spinning on the mule, which contains from 300 to 1,000 spindles per pair.

15. Reeling the yarn intended for the warp.

16. Warping it, and putting it on the beam for the loom.

17. Sizing the warp with animal gelatine, to facilitate the weaving.

18. Weaving at the power-loom or handloom.

19. Scouring the cloth with fuller's-earth, to remove the oil and size.

20. Dyeing, when piece-dyed.

21. Burling, to pick out irregular threads, hairs, or dirt.

22. Milling or fulling, with soap and warm water, either in the fulling-stocks or in the improved milling-machine, where it is squeezed between rollers.

23. Scouring, to remove the soap.

24. Drying and stretching on tenters.

25. Raising the nap of the cloth, by brushing it strongly on the gig, with teazles fixed on cylinders.

26. Cutting or shearing off the nap in two cutting-machines, one cutting lengthwise of the piece and the other across.

27. Boiling the cloth, to give it a permanent face.

28. Brushing, in a brushing-machine.

29. Pressing in hydraulic presses, sometimes with heat.

30. Cutting the nap a second time.

31. Burling and drawing, to remove defects, and marking with the manufacturer's name.

32. Pressing a second time.

33. Steaming, to take away the liability to spot.

34. Folding or cutling for the warehouse.

'These processes, as has been said, are greatly more numerous than those required by any other textile manufacture, and they are performed by a much greater variety of machines and of workpeople.

'It is pretty obvious that there must be proportionate difficulty in effecting improvements which will tell materially on the quantity or the price of the goods produced.'

In another part of his paper, Mr. Baines gives an interesting account of the Shoddy Trade, which is chiefly carried on at Batley, near Dewsbury. He says that 'He must now explain a new branch of the trade, which has risen up with great rapidity and attained extraordinary dimensions, to which, indeed, we are compelled to ascribe much of the present prosperity and extension of the Yorkshire trade. Its origin dates as far back as 1813, but it was long regarded with disapprobation as a dishonest adulteration. It consists in mixing with wool, in the course of manufacture, a very inferior species of wool, made from the tearing-up of old woollen and worsted rags, and to which the names have been given of *shoddy* and *mungo*. Shoddy is the produce of soft materials, such as stockings, flannels, &c., and mungo of shreds or rags of woollen cloth. The latter is of very superior quality to the former, being generally fine wool, which, after being once manufactured and worn, is torn up into its original fibres (by cylindrical machines armed with teeth), only shorter and feebler, and not susceptible of being dyed a bright colour. Both shoddy and mungo give substance and warmth, and the latter will receive a fine finish; but, from the extreme shortness of their fibre, the cloth made from them is weak and tender. If cloth made of these kinds of rag-wool is expected to have the tenacity of goods made from new wool, it will utterly disappoint; but there are immense quantities of goods where substance and warmth are the chief requisites, and where strength is of no importance. Among them are paddings, linings, the cloth used for loose and rough greatcoats, office-coats, and even ladies' capes and mantles. Broadcloth may be made with a large admixture of these cheap and inferior materials to look almost as well as that made of pure wool; but the goods for which they are more properly adapted are what are called pilots, witneys, flushings, friezes, petershams, duffels, honleys, druggets, as well as blankets and carpets.

The price of shoddy varies from $\frac{3}{4}d.$ per pound to $5d.$, and the white shoddy from $2d.$ to $10d.$ per pound. The proportions of these materials used in this district are about one-third mungo and two-thirds shoddy. Some goods, such as low-coloured blankets and pea-jackets, are made with only one part of pure wool to six parts of shoddy; but in the whole district perhaps one-third of wool may be used with two-thirds of shoddy or mungo.

It is one of the objects of improvements in the useful arts to give value to that which possessed no value, to utilise refuse, to economise materials, and, as it were, to prolong their existence under different forms to the latest date. The waste swept up from the floor of the cotton mill is made into beautiful paper. The oil washed out of

woollen cloth is now extracted from the muddy liquid which formerly ran to waste, and is saved for fresh oleaginous uses. Scraps, shavings, dust, the contents of sewers, are all made valuable. Why, then, should not the wool of the sheep undergo a second manufacture? If the cloth made of shoddy and mungo is sold for what it really is, no one is deceived. It may, indeed, be fraudulently sold for what it is not, and the man who does so ought to be branded as a cheat. But if the use of shoddy and mungo will answer nearly as well as wool for a vast variety of purposes, and will enable the consumer to obtain two or three yards of cloth where he formerly obtained only one, it should be received as a lawful and valuable improvement in manufacture.

The place where shoddy was first used in this manner was Batley, by Mr. Benjamin Law; and the first machines for tearing up the rags were set up by Messrs. Joseph Jubb and J. and P. Fox. The manufacture has forced its way, and made Batley, Dewsbury, and the neighbourhood the most prosperous parts of the woollen district. There are now in Batley alone fifty rag-engines in thirty-five mills, producing no less than 12,000,000 lbs. of rag-wool per annum (after deducting for loss of weight in the manufacture); and I am assured, on good authority, that three times this quantity is made in the district. The rags are gathered from all parts of the kingdom, as well as imported regularly from the Continent, America, and Australia. There is now a considerable manufacture of the shoddy, or rag-wool, in Germany, and it is believed that no less than 9,000,000 or 10,000,000 lbs. weight were imported last year.

How profitable this trade is to the workmen may be inferred from evidence which has been obtained, to the effect that 5,408 operatives in Batley received 812*l.* of weekly wages, or an average of 14*s.* 1*d.* each.

Another method of cheapening cloth has also been extensively introduced in the woollen manufacture, though by no means to the same extent or with the same success as in the worsted—namely, the use of cotton warps. This also was regarded as a great deterioration of the fabric, and to some extent it is so. The cloth is not so warm as when made all of wool, and it has a certain harshness of feel; but it is not, like shoddy cloth, tender: on the contrary, it is stronger than if made entirely of woollen yarn. Many kinds of goods of great beauty are thus made, among which may be mentioned the tweeds used for trousering, and grey cloths used for ladies' mantles and other purposes. Cloths with cotton warps are generally called union-cloths.

With respect to the value of the woollen manufacture of the United Kingdom, Mr. Baines's estimates are as follow:—

Estimated Annual Value of the Woollen Manufacture of the United Kingdom, 1858.

		£
(1) Raw material—		
75,903,666	foreign and colonial wool	4,717,492
80,000,000	British wool at 1*s.* 3*d.* per lb.	5,000,000
45,000,000	Shoddy and mungo — 30,000,000 lbs. shoddy at 2½*d.* per lb. ; 15,000,000 ,, mungo at 4¾*d.* ,,	609,370
	Cotton and cotton warps, $\frac{1}{10}$ of the wool	206,537
200,903,666		10,533,399
(2)	Dye-wares, and soap	1,500,000
(3)	Wages—150,000 workpeople at 12*s.* 6*d.* per week	4,875,000
(4)	Rent, wear and tear of machinery, repairs, coal, interest on capital, and profit—20 per cent. on the above	3,381,680
	Total	£20,290,079

NO. III.

On the subject of the manufacture of armour plates as practised at the works of Messrs. John Brown & Co., Sheffield, we may refer to the following extract from the letter of The Times' Correspondent.

THE visitors were then conducted through the extensive new and old mills and workshops, where some 3,000 hands were busily engaged in melting, bending, hammering, and twisting great masses of seething iron into every conceivable form its stubborn nature could be made to take. It was really a wonderful sight. On every side, amid thick smoke and deafening clamour, the blazing rites of Moloch—the furnace god of old—were being celebrated. Great furnaces blaring in the fierce white glare which shone from their crevices were stuffed to the mouth with monstrous cranks and shafts and uncouth bosses of red-hot metal. Every now and then some one of them was opened, with a flash that filled the smoky atmosphere with a glare as from snow, and a mass of metal, seething and spluttering in a blaze of sparks, was dragged off and moulded, like so much wax, under the blows of steam-hammers that made the earth tremble and the whole building to jump and chatter under the stroke, as if from the shock of a little earthquake. It was wonderful to see the skill with which the groups of workmen, uniting all their individual exertions in a series of violent efforts like a weird species of dance, contrived to hedge and move about the great masses on the anvils, so that the hammer struck only where and how they chose. While the heat lasted in the mass, and that was for a long time, they never paused or slackened in their work, and though literally almost scorched by their proximity to red heaps, they kept on toiling till the work was done; and the lump that a quarter of an hour before was almost melted iron was picked up by some huge crane that came travelling along the smoky walls, and carried off, glowing through the gloom, a finished piece of work. At other places there were tilt and lever hammers wearying the very air with the clattering din of their tremendous strokes. At others, great ingots of steel were cast by the Bessemer process—small plates were rolled and roughly cast aside in great red slabs to cool, or hurried backwards and forwards in iron trucks, scorching even the hardened workmen out of their tracks as they came burning past. On every side there were furnaces and smoke and red-hot metals, while in out-of-the-way nooks men in steel caps and wire vizors, and cased below in rough steel leggings, like jackboots of iron, fought in a cloud like so many salamanders round some rough

mass that was dangerous in its fierce heat, and which sent back aggressive spurts of red-hot metal in return for every blow. Such fiery combats as these were going on in all directions; the 'Sheffield carpet' of the factory—iron plates—was hot and painful to the feet; the air was arid with a sulphury warmth that was like the glow of an overheated stove. When we have said thus much, and added that there were roaring pipes of steam mounting into the air, side by side with great iron trumpet-shaped piles of chimneys, out of which jets of red flame roared and flapped into the smoke above like gigantic flambeaux—that lower down long lines of lathe-bands flew noiselessly in all directions, and that the background was filled in with glimpses of ponderous fly-wheels whirling their arms through the smoke and turning rolling-mills or lapping-hammers, or shearing down with noiseless might the great lumps of iron that were brought in to be cut up,—we have said enough to indicate the view which met visitors on their first introduction to this glowing scene of industry. Though not the first, yet by far the most important process which their Lordships were shown, was the operation of rolling the great plate—by far the largest single plate that has ever yet been rolled in the world. This took place in what are called the New Mills of the Atlas Works, which were used on Thursday for the first time, and where great ranges of furnaces have been erected, with their mouths opening on the iron tramway which leads direct to the double rollers through which the plate passes. One may guess at the solidity required for mills of this kind when it is stated that some of the rolls used at this mill on Thursday have a first foundation of no less than 60 tons of solid iron, resting on masonry carried far below the earth. The rolls themselves are 32 in. in diameter and 8 ft. wide, and are turned by an engine of 400 horse-power, putting in motion a fly-wheel large enough, apparently, to make a world rotate if only well balanced on its axis. A powerful screw, applying its force through compound levers, allows the distance between the rollers to be adjusted to the fraction of an inch, so that the plate which on its first rolling is forced through an interval of—for instance, 12 inches apart—is on its next wound through one of 10, next through one of 8, and so on till the required thickness has been carefully and equally attained by tremendous compression through every part of the metal. There were a great many visitors to see the rolling of this formidable mass, which was fortunate, as one would certainly be frightened to witness the terrible process alone. After some delay and quick glimpses made by the most hardened workmen, who, rushing up to the door of the furnace, got a half-blinded glance into its white interior, it was decided that the mass was ready; for,

strange as it may seem, an armour-plate requires more than mere heating, and has to be cooked and watched in its cooking with as much care as if it were an omelette, and the plate that is drawn before it is 'done to a turn' generally remains a permanent ornament of the unlucky manufacturer's workshop, which no one will have at any price. When at last this eventful moment had arrived, on Thursday, the door of the furnace was slowly raised, and a colossal pair of pincers with very long handles, fastened to a chain drawn by machinery, was swung in. For an instant some men rushed forward, and, shielding their faces from the deadly heat that shot from the furnace, adjusted the bite of these forceps on the plate, and then ran back as the chain began to tauten, and the great inmate of the blazing den was slowly dragged forth on to the long iron trucks in front of the door, and there lay in its huge length and thickness a mass of living fire, which none could approach, or scarcely even look at, so fierce was its glow and terrific heat. The chains that should have pulled it forthwith to the rollers were too slack; and then arose shouts and cries and commands, as the men did battle with this mass of fire, coming so near it, in their attempts to gather up the slackened chains, that one literally almost expected to see them fall, scorched and shrivelled, on the ground. In its great glare they fought and struggled with the chains till at last all was adjusted, and the great pile of angry fire began to move slowly downwards towards the mills, the men following it with hoarse shouts and directions, now hid in steam, as buckets of water were dashed over the mass, and the next moment standing in an atmosphere of white light, to which the light of the day around was mere dusk. The rollers did not bite directly the mass came to them; and when they did, the engine was almost brought to a standstill by the tremendous strain upon it: but at last the soft plate yielded, and the rollers seemed to swallow it as they wound it slowly in, squeezing out jets of melted iron like squirts of fire, that shot about dangerously as the pile was compressed from 19 inches to 17 inches thick by the irresistible force of the rollers. *Ce n'est que le premier pas qui coûte*, and the victory was certain when the mass had once passed through the mill, and both visitors and workmen gave a tremendous cheer at the success. From this time it was kept rolling backwards and forwards, the workmen sweeping from its face the scales of oxide that gathered fast upon it with long-handled besoms that, though soaked in water, caught fire and blazed up as fast as they were used. With every time it was passed through, the rollers were screwed closer and closer together, as we have already mentioned, till at the end of about a quarter of an hour, after leaving the furnace an almost melted mass, it was passed through for

the last time, and came out opposite the furnace-door it had so lately left, no longer shooting forth spiteful sparks, but shorn of half its heat, subdued and moulded to its proper form—a finished armour-plate, weighing 20 tons, 19 ft. long, nearly 4 ft. wide, and exactly 12 in. thick throughout from end to end. This is the most signal triumph that any rolling-mills have yet achieved.

Other smaller plates were then rolled with a quickness and certainty that proved the skill already gained in this new and most important branch of manufacture. One plate was 17 feet long by 4 feet broad and 5½ inches thick; one, 19 feet long by 4½ feet wide and 4½ inches thick; one we have already alluded to, 41 feet long by 3 feet 10 inches broad and 4½ inches thick. A lesser plate was also rolled 18 feet long, 5 feet wide, with a thickness of 6 inches on one edge and 3 inches on the other.

The method of converting cast iron by the Bessemer process into the tough soft Bessemer metal, a combination of the qualities between soft steel and tough wrought iron, was next shown. It is needless now to enter on a description of the very beautiful and very terrible process, to witness, which the metal goes through in the converter as it is stimulated to a white heat by the passage of the air blown by force-pumps upwards through the mass. No fireworks can surpass the brilliancy of the display this process affords as it approaches its completion, and the stream of violet flame and clouds of burning sparks pour from the mouth of the converter as from a gigantic squib. Nor is it necessary here to enter into a detail of the now well-known process, which was a subject of such controversy a few years since, but which is now being so generally and advantageously adopted throughout England and the Continent. Suffice it to say, that in twenty minutes from the time of putting in the charge of cast iron, it was, without any expenditure of labour, poured out into the mould, an ingot of soft tough steel weighing three tons. This metal, after undergoing hammering, is now most extensively used for steel rails at stations, points, and junctions, where the wear is great, and in these trying situations it seems almost indestructible. A great deal has also been used in making Blakeley rifled guns in this country for both Federals and Confederates. These are the ordnance which the Americans always speak of as Parrott guns, and by them they are more highly prized than those of either Armstrong or Whitworth. Yet it is stated that the Ordnance Select Committee have refused even to try these guns at Shoeburyness. After these processes were over, and the various planing and filing shops had been duly examined, the visitors were entertained by Mr. Brown at a most sumptuous *déjeuné*.

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